RADC-TR-72-140
Technical Report
April 1972

LASER ABSORPTION IN THE 5 MICRON BAND
(3271-2)

The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

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1. ORIGINATING ACTIVITY (Corporate author) ElectroScience Laboratory Department of Electrical Engineering, The Ohio State University, Columbus, Ohio 43212	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

LASER ABSORPTION IN THE 5 MICRON BAND

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Quarterly Report ~~June~~ 23 - December 23, 1971

5. AUTHOR(S) (Last name, first name, initial)

Ford, Dale L.

6. REPORT DATE April 1972	7a. TOTAL NO. OF PAGES 48	7b. NO. OF REFS 9
8a. CONTRACT OR GRANT NO. F30602-72-C-0016	9a. ORIGINATOR'S REPORT NUMBER(S) ElectroScience Laboratory 3271-2	
b. PROJECT NO.		
c. TASK	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) RADC-TR-72-140	
d.		

10. AVAILABILITY/LIMITATION NOTICES

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11. SUPPLEMENTARY NOTES Monitored By James W. Cusack, RADC/OCSE Griffiss AFB NY 13440	12. SPONSORING MILITARY ACTIVITY Advanced Research Projects Agency 1400 Wilson Blvd Arlington VA 22209

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DD FORM 1 JAN 64 1473

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	ROLE	WT	ROLE	WT	ROLE	WT
CO laser Atmospheric transmittance Water vapor absorption						

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LASER ABSORPTION IN THE 5 MICRON BAND

Dr. Dale L. Ford

Contractor: The Ohio State University
ElectroScience Laboratory
Contract Number: F30602-72-C-0016
Effective Date of Contract: 23 June 1971
Contract Expiration Date: 23 June 1972
Amount of Contract: $65,000.00
Program Code No. OE20

Principal Investigator: Dr. Ronald Long
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This research was supported by the Defense Advanced Research Projects Agency of the Department of Defense and was monitored by James W. Cusack, RADC (OCSE), GAFB, NY 13440 under Contract F30602-72-C-0016.

FOREWORD

This report, OSURF Report 3271-2, was prepared by The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering at Columbus, Ohio. Research was conducted under Contract F30602-72-C-0016. Mr. James W. Cusack, RADC (OCSE), of Rome Air Development Center, Griffiss Air Force Base, New York, is the Project Engineer.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact

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Atmospheric transmittance calculations are made for five atmospheric models with water vapor as the molecular absorber. Transmittance plots are shown for these models in the spectral region of 1840 to 1990 cm^{-1}. The effect of varying some of the parameters involved in the calculation of atmospheric transmittance is investigated at several CO laser wavelengths.

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I. INTRODUCTION

This is the second quarterly report on Contract Number F30602-72-C-0016, entitled "Laser Absorption Studies in the 5 Micron Band, for the period September 23 to December 23, 1971. The objectives of this contract are to perform laboratory measurements and theoretical computations in order to determine values of atmospheric transmittances at CO laser wavelengths. The technical accomplishments during this period are described in this report. In Chapter II the expansion of the computer programs to calculate atmospheric transmittances is described. Additional calculations have been made for five atmospheric models and parametric studies were made to determine the influence of different parameters upon the calculations. The current experimental setup is described in Chapter III. The CO laser was obtained near the end of the work period and initial measurements were made in addition to investigating optimum techniques for data acquisition.

II. TRANSMITTANCE CALCULATIONS

Three computer programs were described in the first quarterly report.[1] One program calculates the molecular absorptance for given frequencies along horizonal paths where the temperature, pressure, and concentration of the molecular absorber are constant in the optical path. This program is called LEVEL. The second program is called SLANT and calculates the absorptance due to water vapor for given frequencies for optical paths where the temperature, the total pressure and the partial pressure of water vapor are variable. The third program, TRANSPLOT, produces, for a given frequency range, pressure, temperature, absorber concentration, and path length, a plot of the absorption spectrum. The conversion of these programs was completed so that they can be used on the ElectroScience Laboratory Computer. The advantages of using this system are the faster turnaround time and lower cost. These programs have also been modified so that the absorptance of several molecular absorbers in the optical path can be calculated simultaneously. Additional calculations using these programs are described below.

Input data for these calculations has been taken from References 2 and 3.

Model Calculations (TRANSPLOT)

Theoretical absorptance plots were made for the sets of conditions found at seven different altitudes for the 30°N July atmospheric model. At each altitude 3 plots were made to cover the spectral range from 1840 - 1990 cm^{-1}. These plots are shown in Figures 1 through 21.

SLANT

Calculations were made for 5 atmospheric models and for 25 laser lines. The atmospheric models were taken from the ESSA atmospheric data.[2] The models were 15°N Annual, 30°N July, 45°N July, 60°N July, and 75°N July. The laser lines were chosen on the basis of best transmittance at zero altitude for 30°N July. The only absorber used in the calculation was water vapor. The water vapor lines used included all those between 1750 cm^{-1} and 2146 cm^{-1} given by Benedict and Calfee.[3] All of these lines were used for each laser line calculation. These calculations are of the format of Table 3 of the first quarterly report[1] and are not reproduced here (125 pages).

Bar Graphs

The 25 laser lines were chosen, as stated above, on a basis of best transmittance for a given set of conditions. Due to the fact that the absorption line shapes and strengths change as a function of both pressure and temperature it is necessary to give the conditions used when stating an order of best transmittance for a group of lines. To demonstrate this statement, bar graphs were prepared which show the extinction coefficient for sets of conditions found in the atmospheric models used in the SLANT calculations. These are shown in Figs. 22 through 26. The upper plot for each figure shows the extinction coefficients at 10 km altitude and the lower one shows the extinction coefficients

at 0 km altitude for a numbered CO laser frequency. The $30^{o}N$ July, 0 km altitude case is in a strictly decreasing order, since those conditions were used for ordering, but all other cases show where some rearranging would be needed if a decreasing order is to be preserved. The list of 25 lines is given in Appendix B of this report.

LEVEL

A series of runs were made with LEVEL at 10 CO laser frequencies for parameters that are typical of those to be used in the laboratory experiment. The relative humidity was varied from 0 to 100%, the temperature from 72^{o} to $76^{o}F$, the optical path length from .1 to 1.0 km and the total pressure from 1/4 to 1 atmosphere. These tables provide guidance in selecting the experimental parameters. These results are not presented at this time but will be included in later reports when the experimental data is being analyzed.

Parametric Studies

Various parameters were varied over a given range in the program LEVEL for the following reasons. First, it was necessary to determine the effect of changes in the strength of the weakest absorber lines included (SLOW) and of the wave-number interval (BOUND) on the calculated transmittances at wavenumbers of the CO emission lines. Next the variation of various parameters was used to estimate the effect of possible errors in the published line data.[3] In addition the recently published data of R. A. McClatchy[4] was used to provide a comparision with our results.

Some of the factors affecting the water vapor absorptance calculations are:

1) The number of lines considered to absorb at the wavenumber of a CO laser emission line. Arbitrarily only lines within a certain wavenumber interval $\pm\Delta\nu$ from the wavenumber ν_o of a given CO laser emission line are assumed to contribute to the absorptance at ν_o. In the computer programs BOUND is this value of $\Delta\nu$ in wavenumbers. Very weak lines in this interval

are expected to have little effect upon the absorptance at ν_o. The program variable SLOW is the lower bound on the strength of the lines.

2) The experimentally determined dependence of the half-width upon temperature for a given absorber and broadening gas varies with the frequency of the transition. For water vapor broadened with nitrogen, Benedict and Kaplan[5] have found a power law dependence of the half-width on temperature and have estimated an average value for all water lines to be 0.62. In the computer programs this exponent is the variable CX.

3) At the higher pressures found in the atmosphere the effects of collision broadening are assumed to produce an absorption coefficient line shape described by the Lorentz formula. At lower pressures a combination of Doppler and collision broadening leads to a Voigt profile (cf. Penner[6]).

4) The absorption line positions affect the absorptance at the wavenumber ν.

Each of these topics is discussed in more detail below. Only one parameter was changed at a time and all calculations were made with the same atmospheric model with water vapor as the only molecular absorber.

Effect of Changing BOUND

The effect of changing BOUND on the calculated absorptance coefficient for the CO laser emission line at 1900.043 cm^{-1} is shown in Figure 27. Absorption coefficients of other CO laser lines show a similiar dependence on BOUND. To obtain reliable calculations it is recommended that BOUND be at least 120 cm^{-1}.

Effect of Changing SLOW

In the spectral region 1700 cm^{-1} to 2200 cm^{-1} there are about 1700 water lines listed in Ref. 3. These range in intensity from .0001 $cm^{-1}/gm\ cm^{-2}$ to 7635 $cm^{-1}/gm\ cm^{-2}$. Neglecting the

weaker lines can speed the calculations but the calculations will be theoretically less accurate. Figures 28 and 29 show the calculated absorption coefficient at 1900.043 cm^{-1} and 1901.779 cm^{-1} respectively. The absorptance at 1900.043 cm^{-1} is caused primarily by the wings of water lines, while the absorptance at 1901.779 cm^{-1} is caused primarily by a nearby water line at 1901.82 cm^{-1} whose strength is 10.82 $cm^{-1}/gm\ cm^{-2}$. Thus for the calculation at 1901.779 cm^{-1} almost no difference in the absorption coefficient is apparent until SLOW is larger than 10.82 $cm^{-1}/gm\ cm^{-2}$. For the calculation at 1900.043 cm^{-1} using an SLOW less than 0.1 $cm^{-1}/gm\ cm^{-2}$ results in a nearly constant coefficient and setting SLOW at 0.1 $cm^{-1}/gm\text{-}cm^{-2}$ eliminates nearly one half of the water lines tabulated in Reference 3 from the calculation.

Effect of Changing CX

The halfwidth of a Lorentz line at temperature T and pressure P is given by

$$\alpha = \alpha_o \frac{P}{P_o} \left(\frac{T_o}{T}\right)^{CX} \tag{1}$$

where α_o is the half-width at temperature T_o and pressure P_o. The effect on the calculated absorption coefficient of changing CX is dependent upon the difference between the reference temperature, T_o and the actual temperature, this effect increases as this temperature difference increases. The half-widths of the water vapor lines given in Ref. 3 list the reference temp as 287.7° K.

The value of the absorption coefficient was calculated for the CO line at 1900.043 cm^{-1} for two temperatures, 301.15 and 311.15° K as a function of CX. Despite the fact that the temperature is only 13.45°C and 23.45°C respectively above the reference temperature, appreciable differences in the calculated absorption coefficient are apparent as seen in Fig. 30.

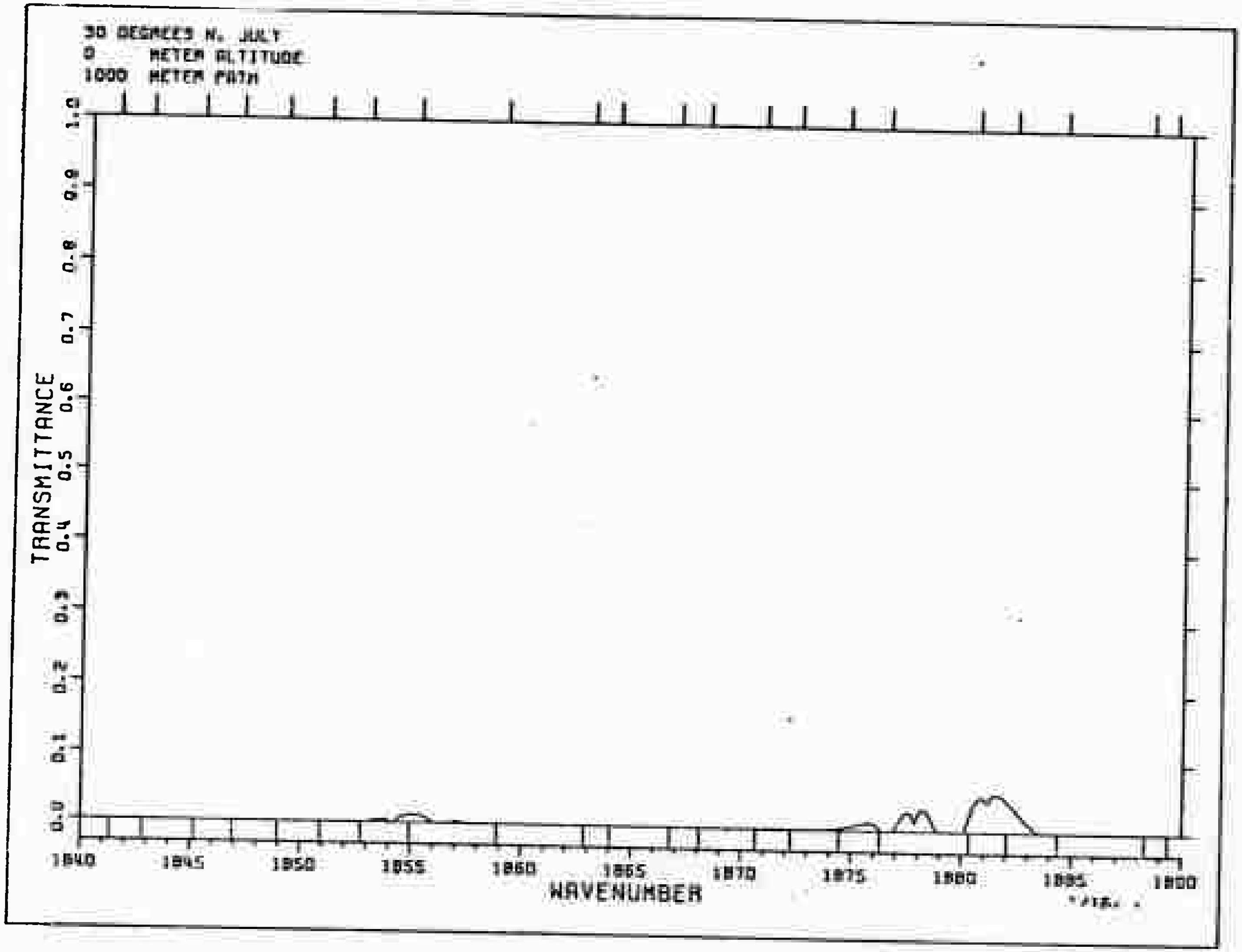


Fig. 1. Theoretical transmittance vs wavenumber for the indicated conditions.

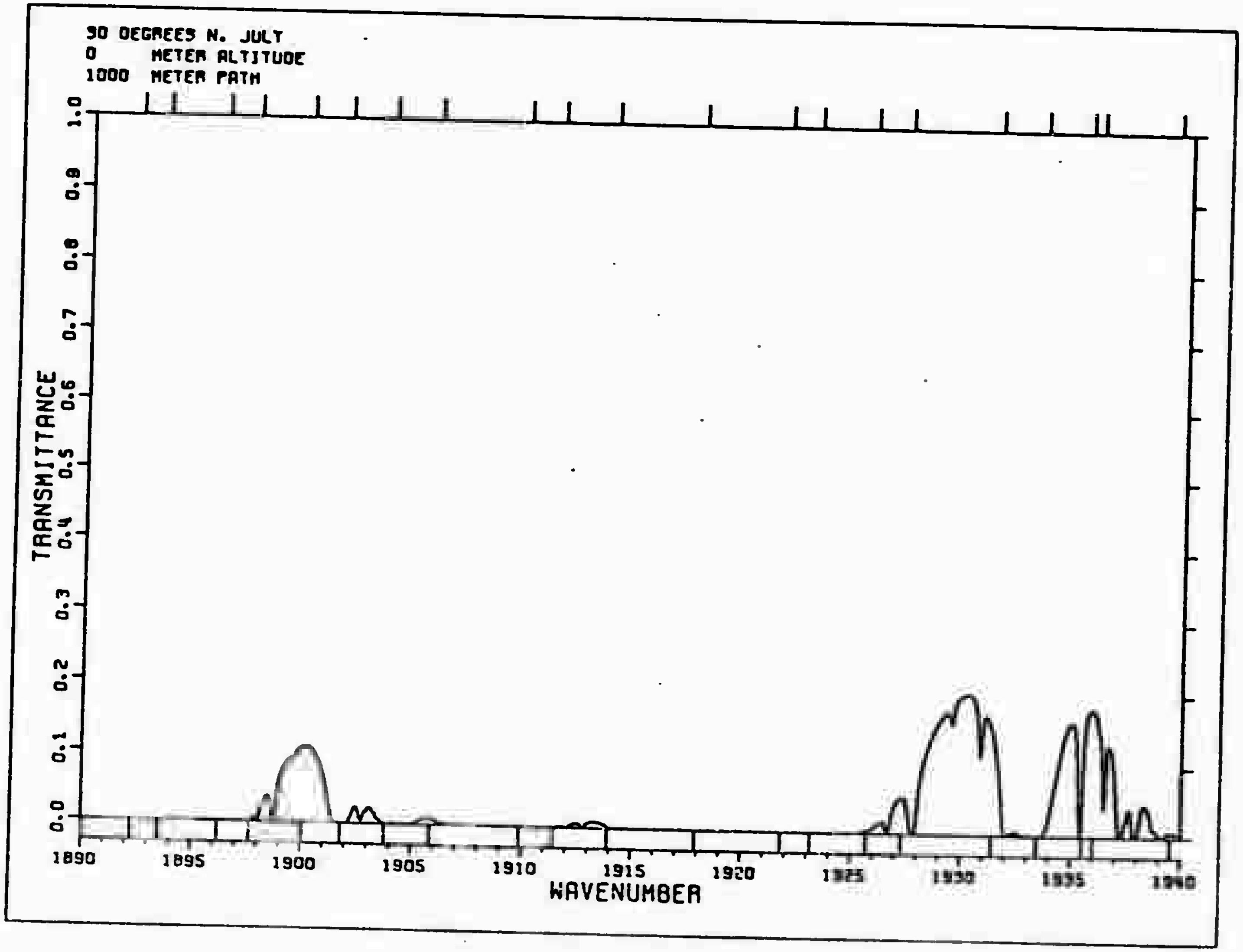


Fig. 2. Theoretical transmittance vs wavenumber for the indicated conditions.

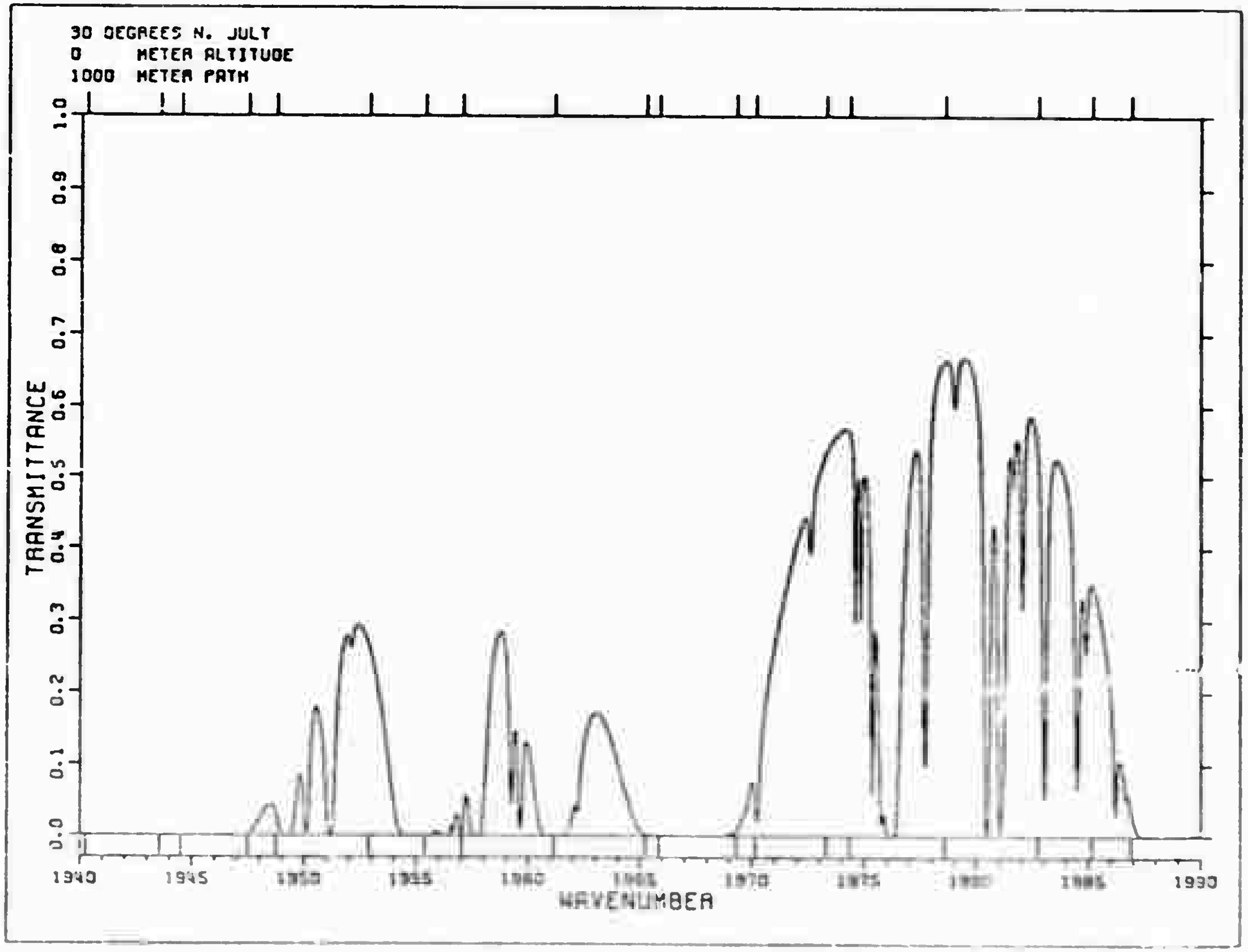


Fig. 3. Theoretical transmittance vs wavenumber for the indicated conditions.

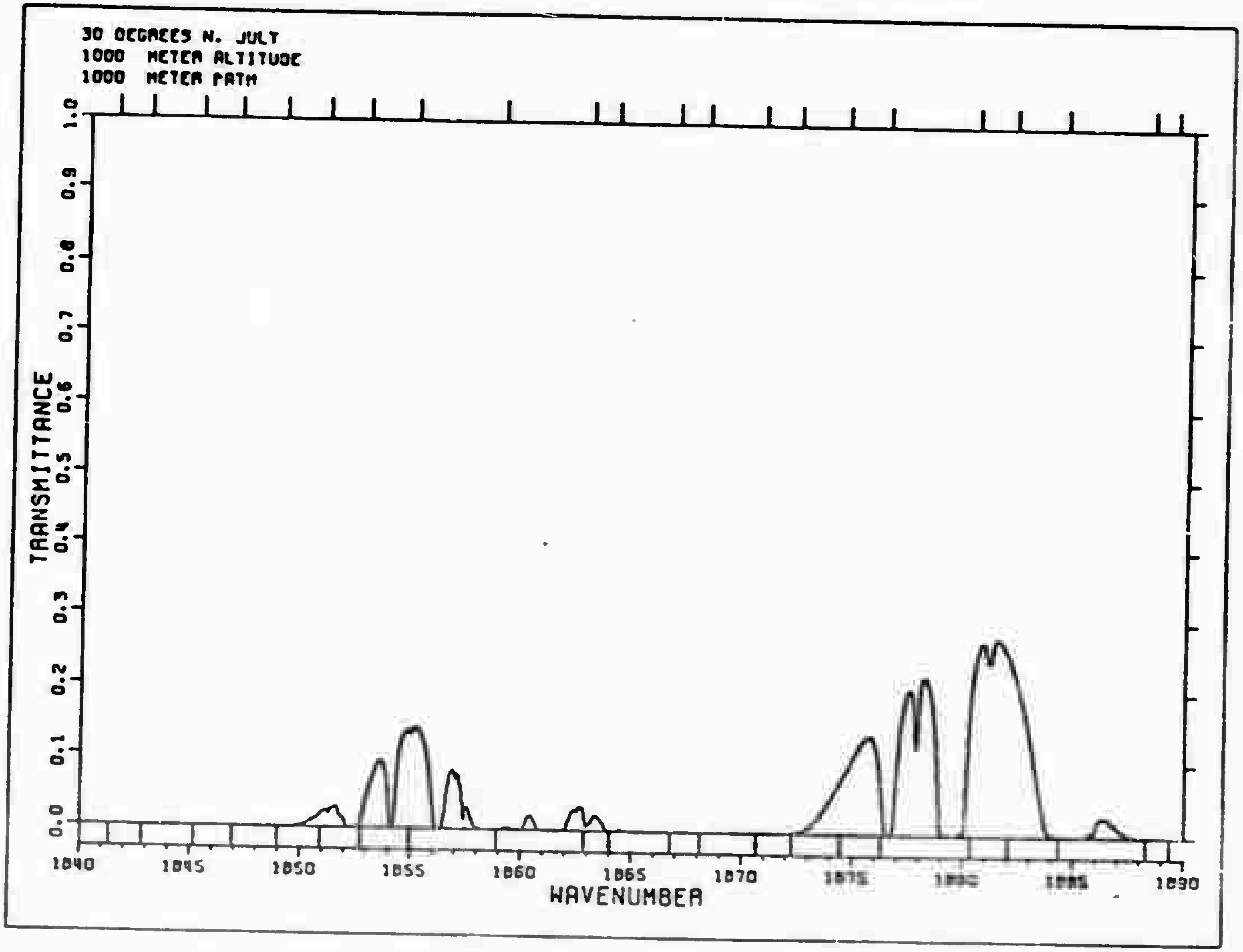


Fig. 4. Theoretical transmittance vs wavenumber for the indicated conditions.

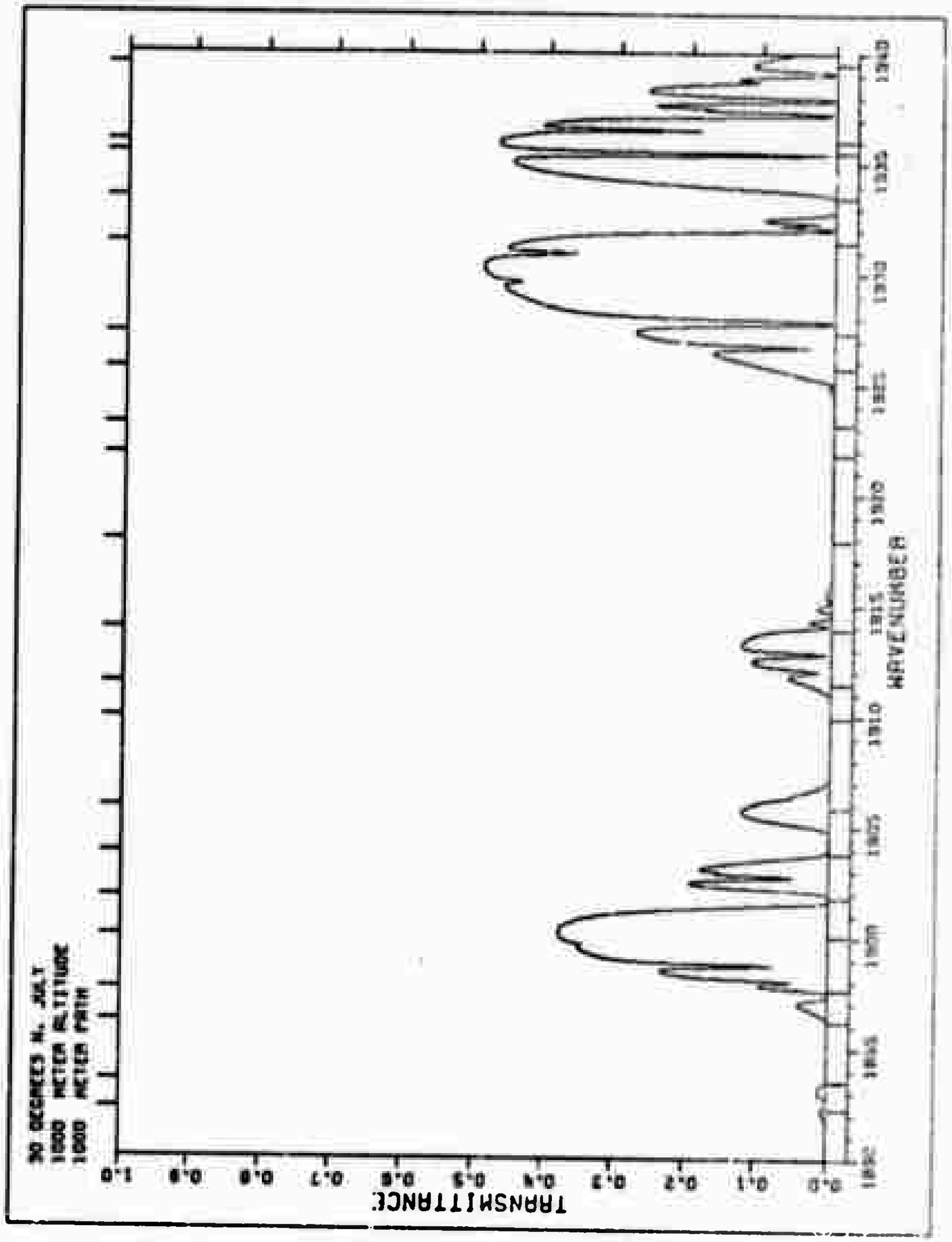


Fig. 5. Theoretical transmittance vs wavenumber for the indicated conditions.

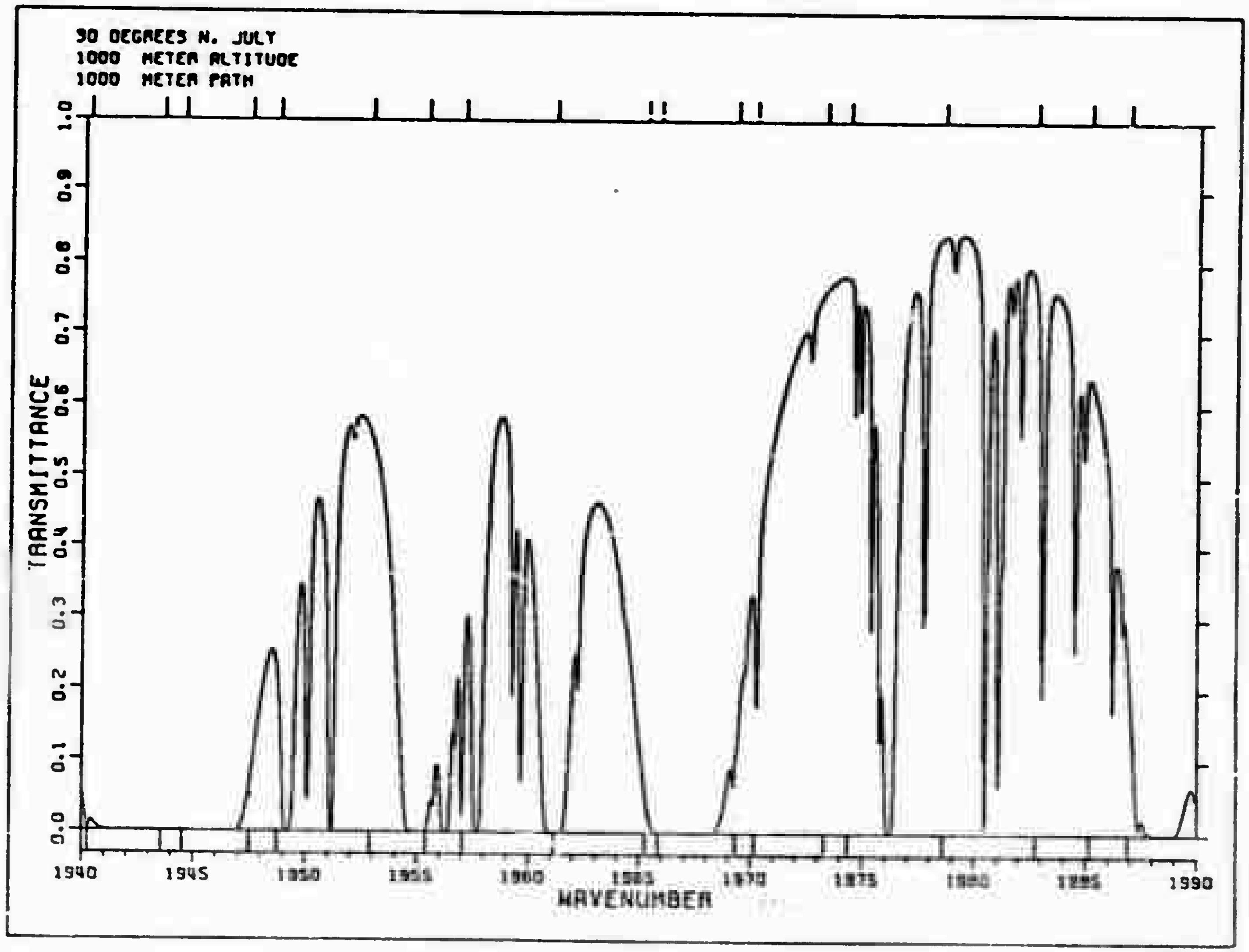


Fig. 6. Theoretical transmittance vs wavenumber for the indicated conditions.

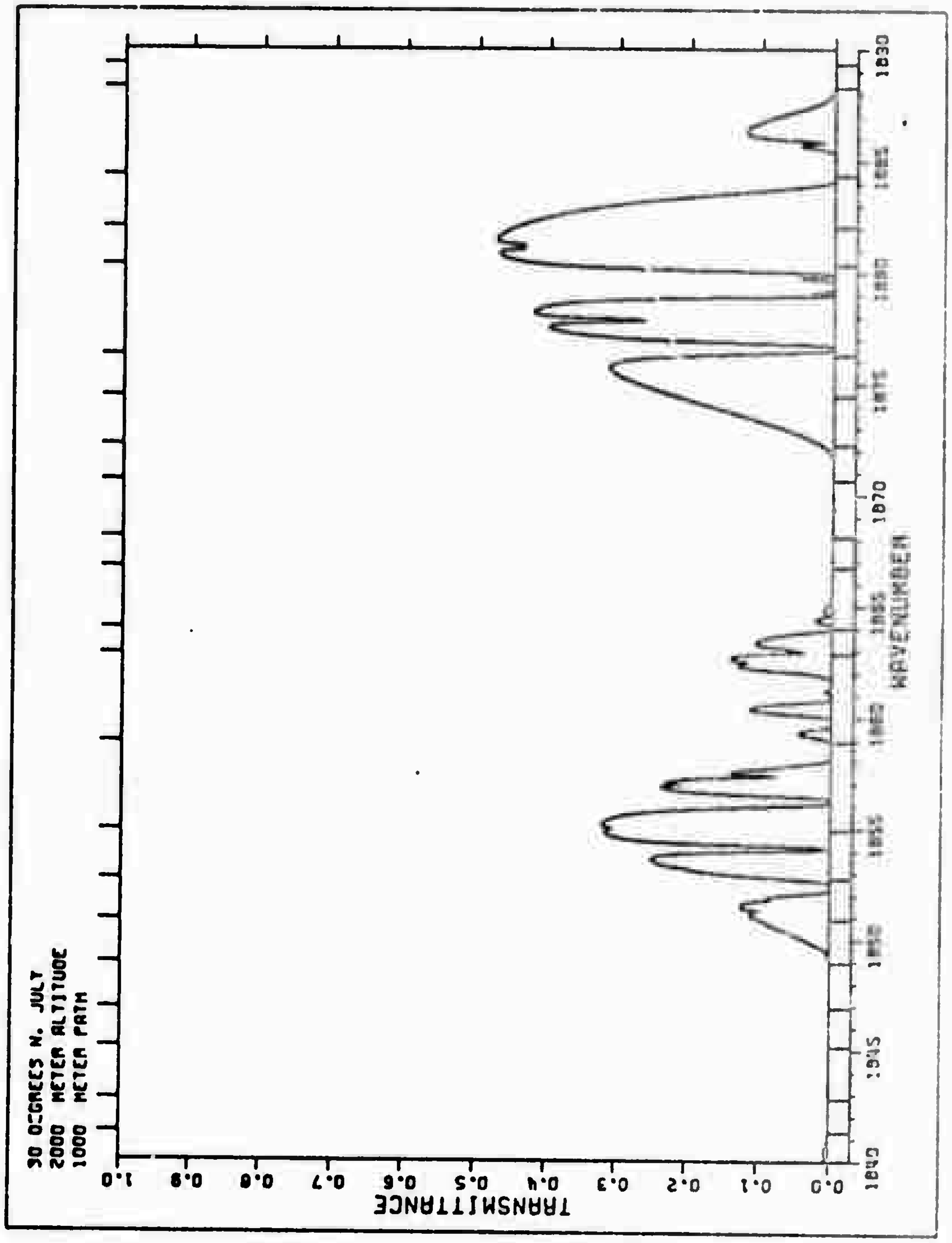


Fig. 7. Theoretical transmittance vs wavenumber for the indicated conditions.

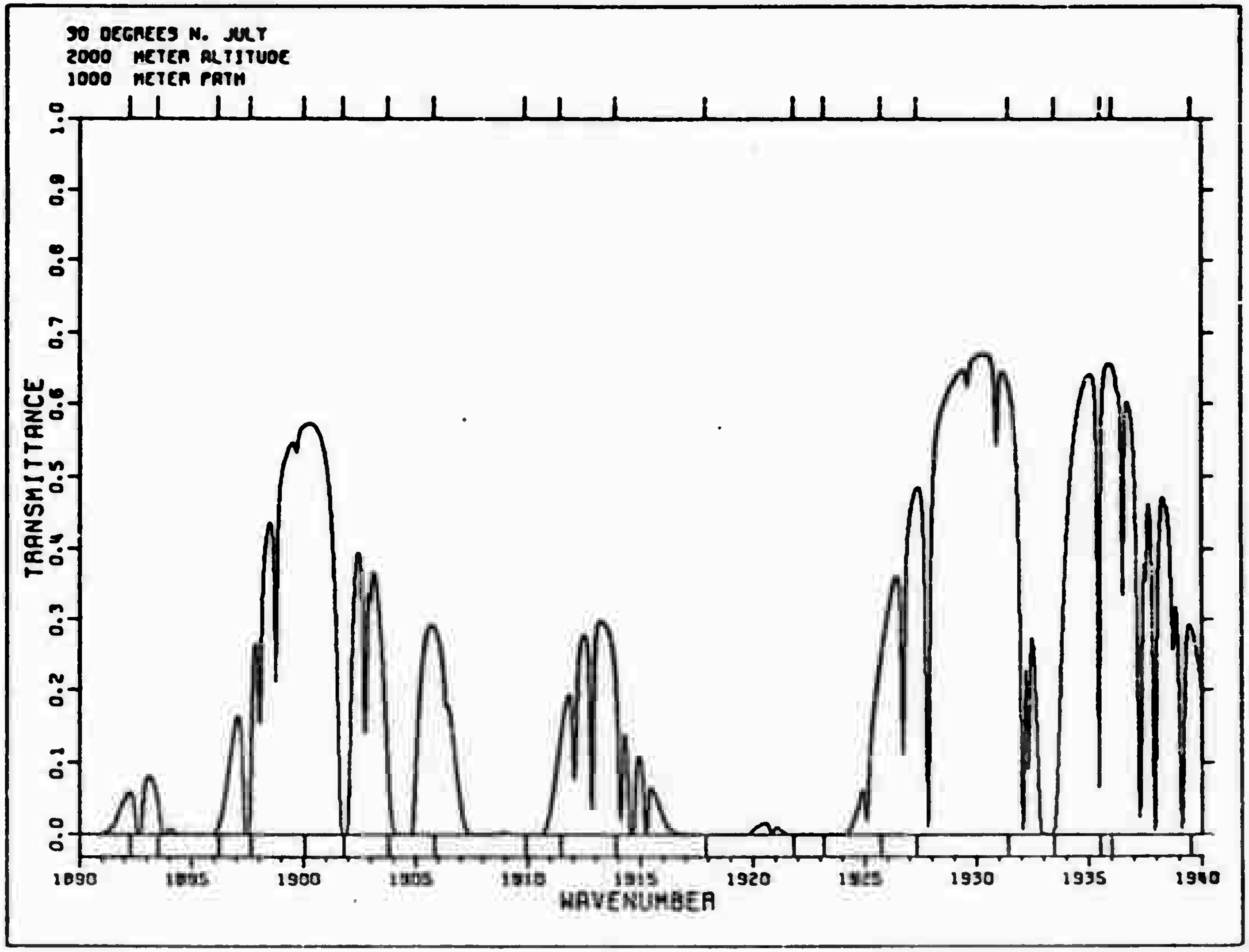


Fig. 8. Theoretical transmittance vs wavenumber for the indicated conditions.

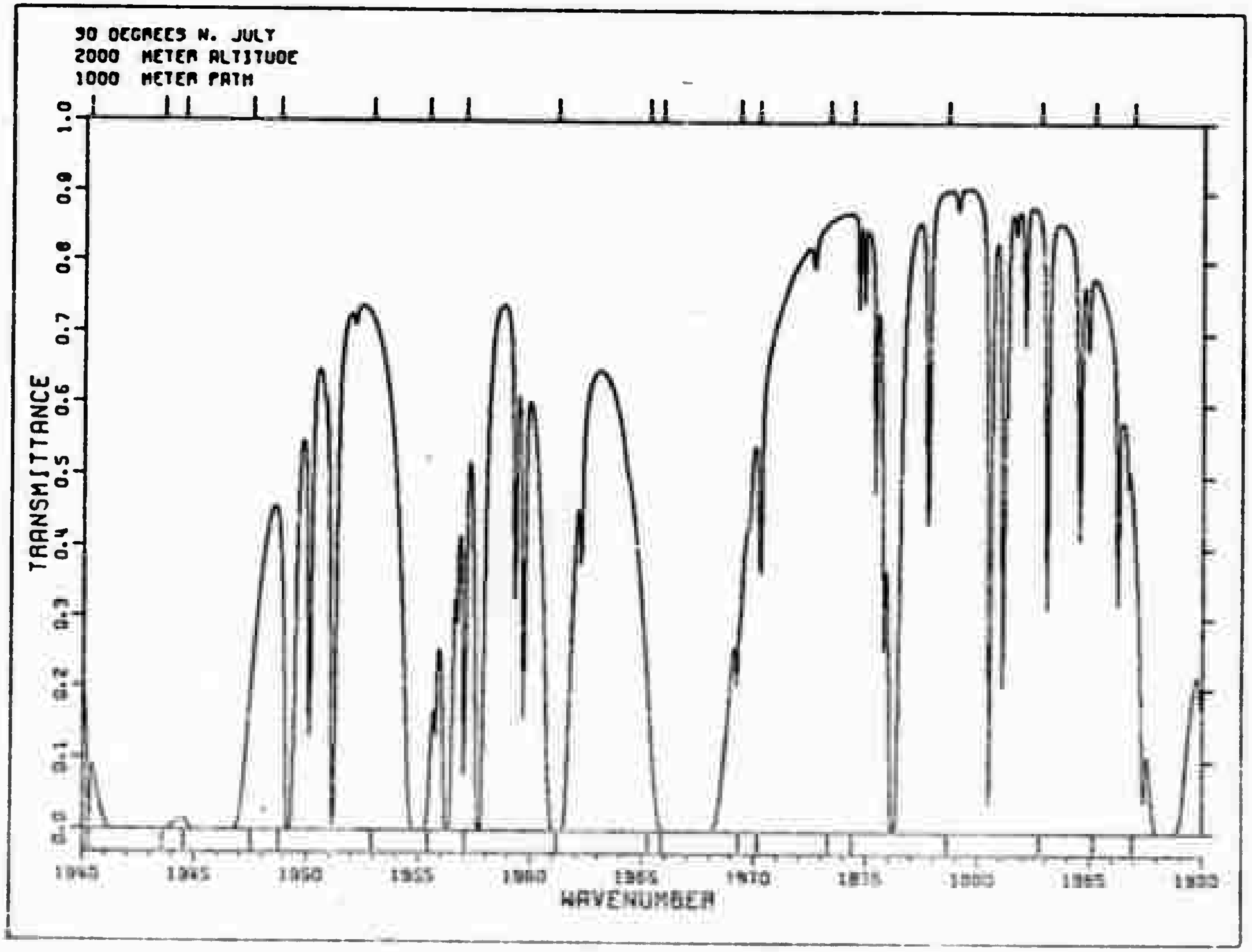


Fig. 9. Theoretical transmittance vs wavenumber for the indicated conditions.

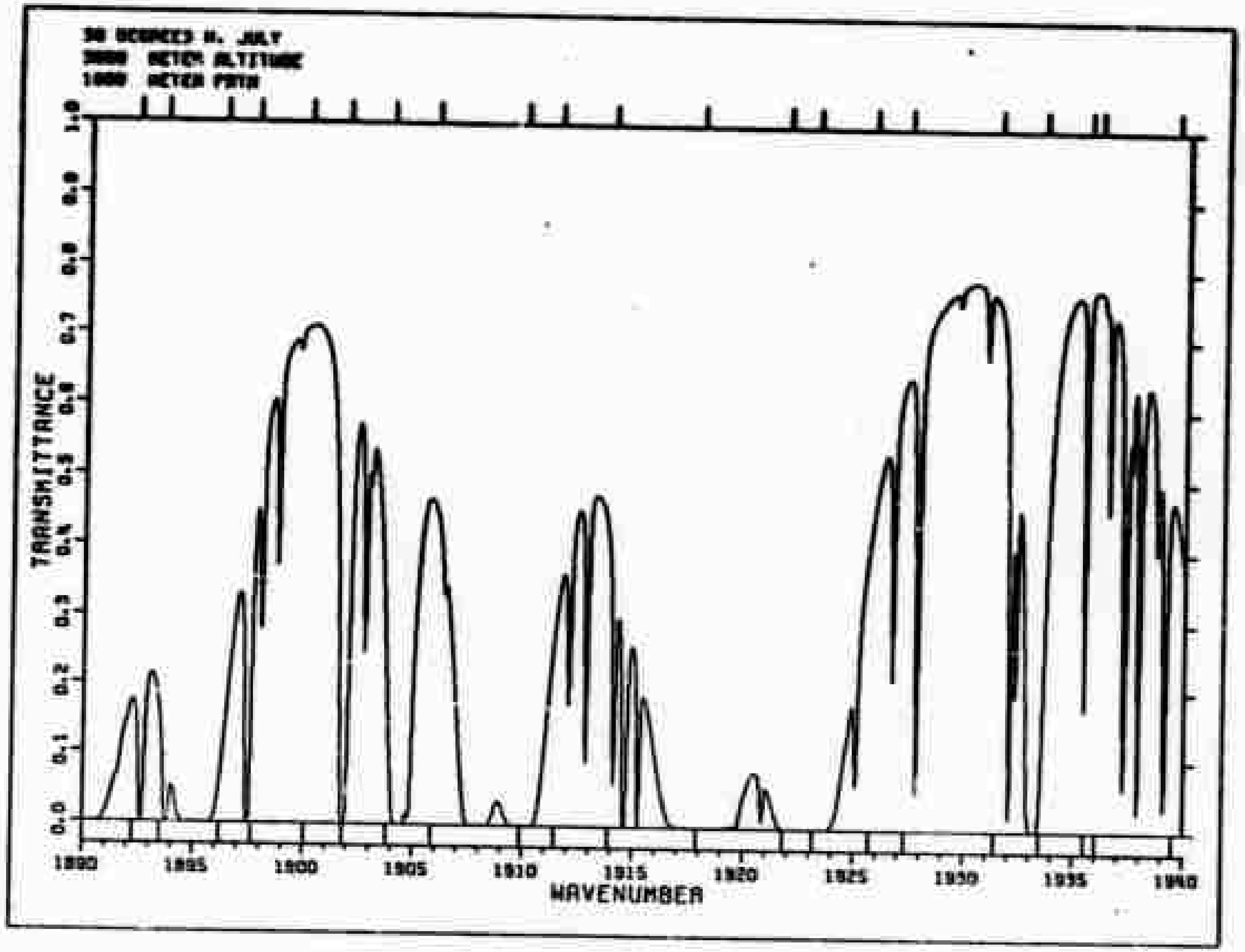


Fig. 10. Theoretical transmittance vs wavenumber for the indicated conditions.

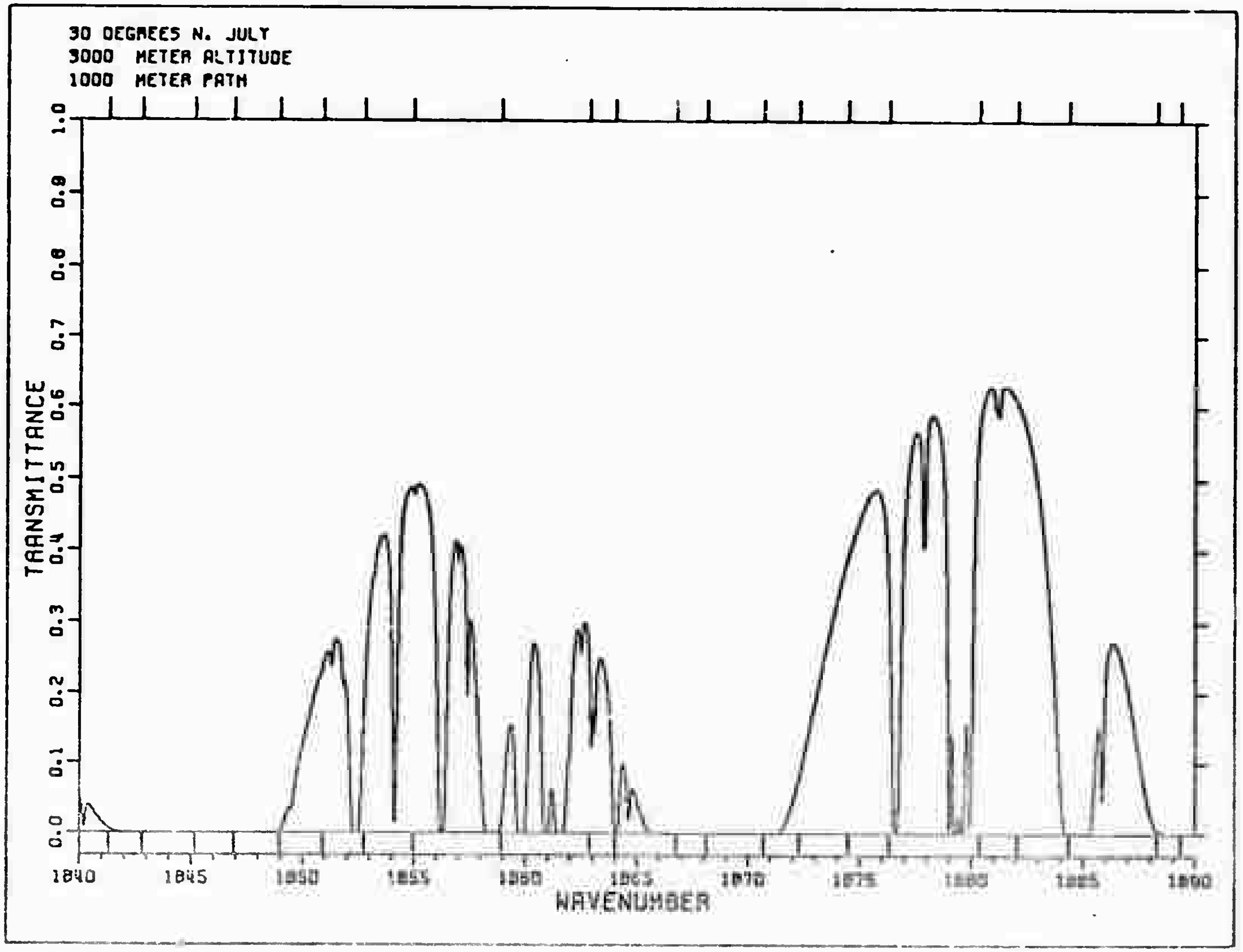


Fig. 11. Theoretical transmittance vs wavenumber for the indicated conditions.

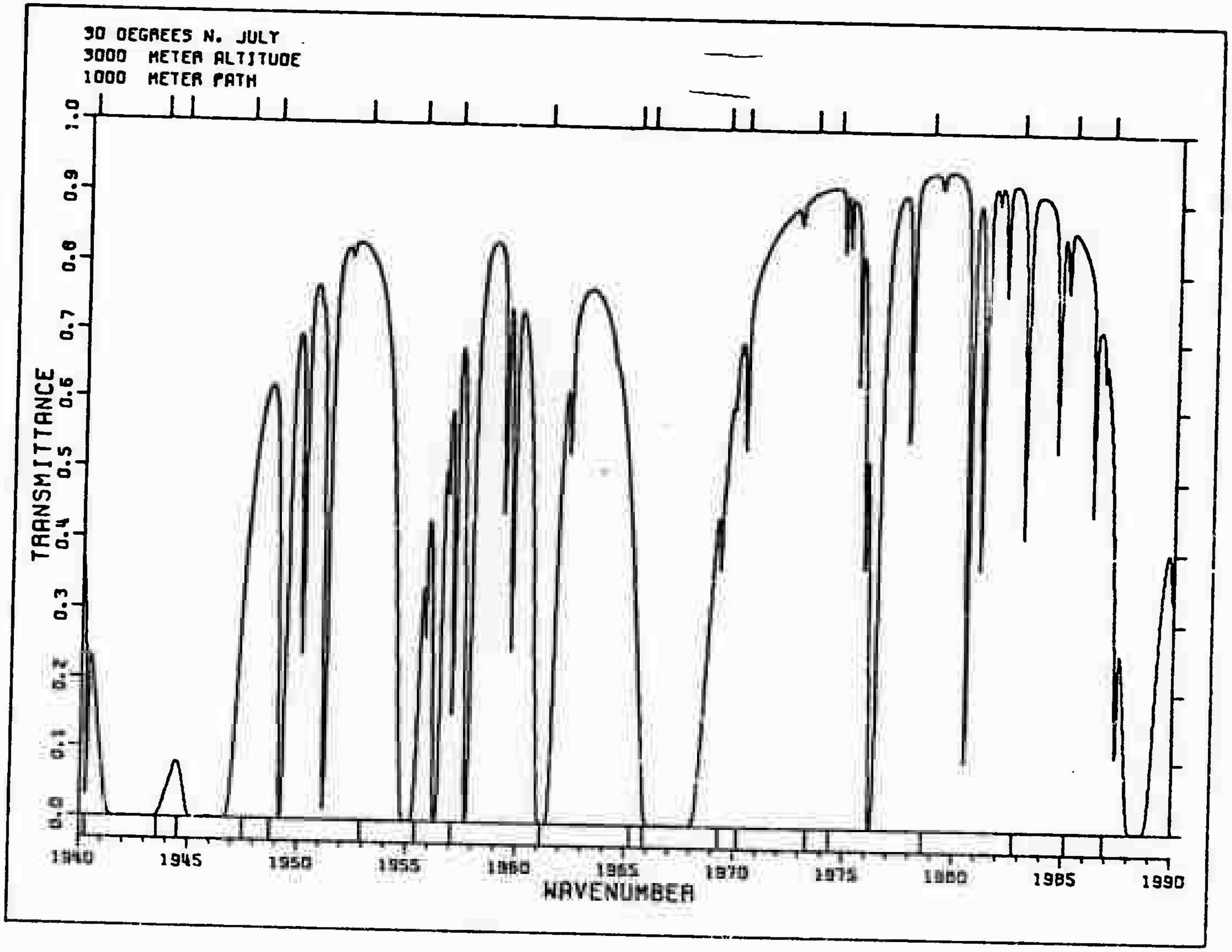


Fig. 12. Theoretical transmittance vs wavenumber for the indicated conditions.

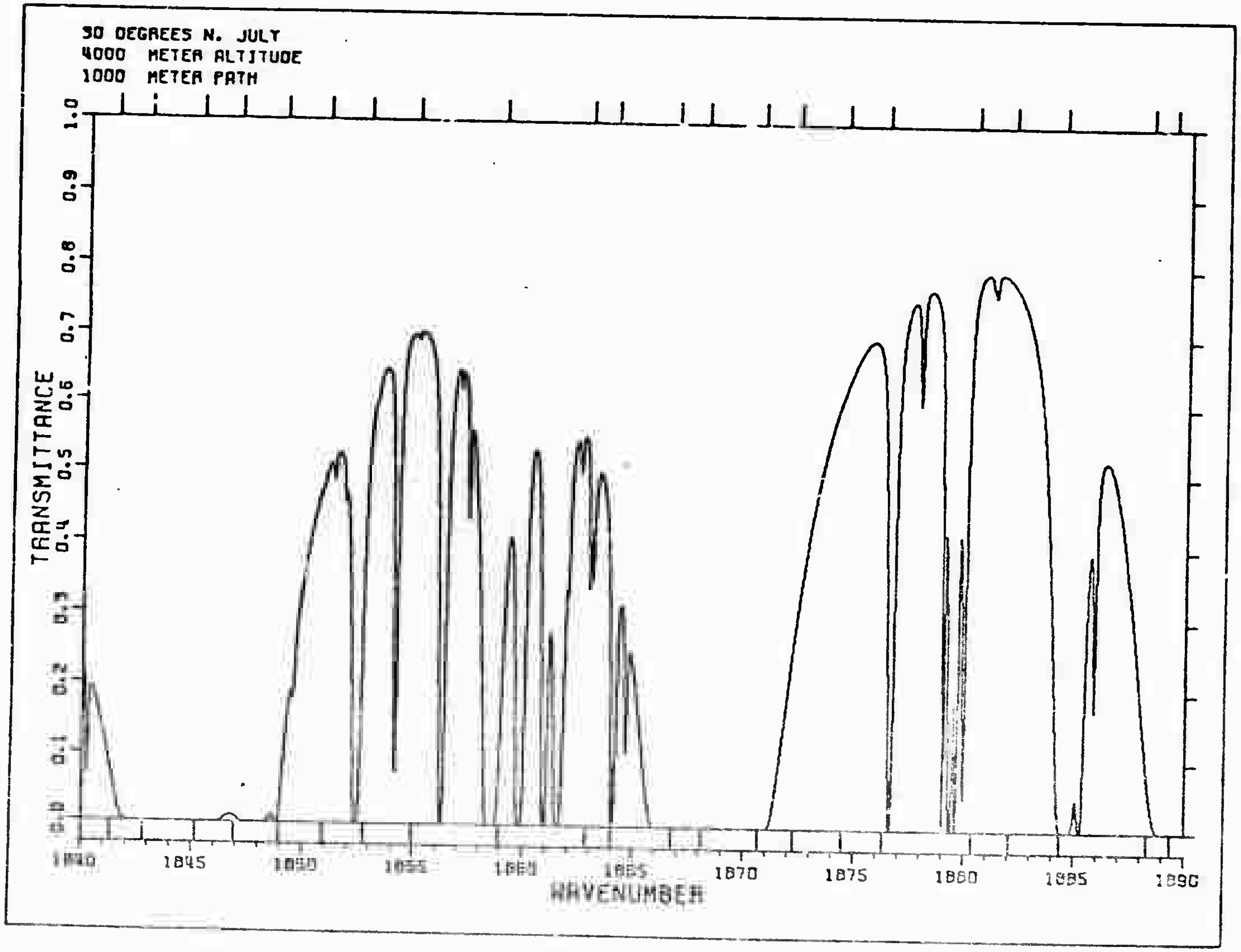


Fig. 13. Theoretical transmittance vs wavenumber for the indicated conditions.

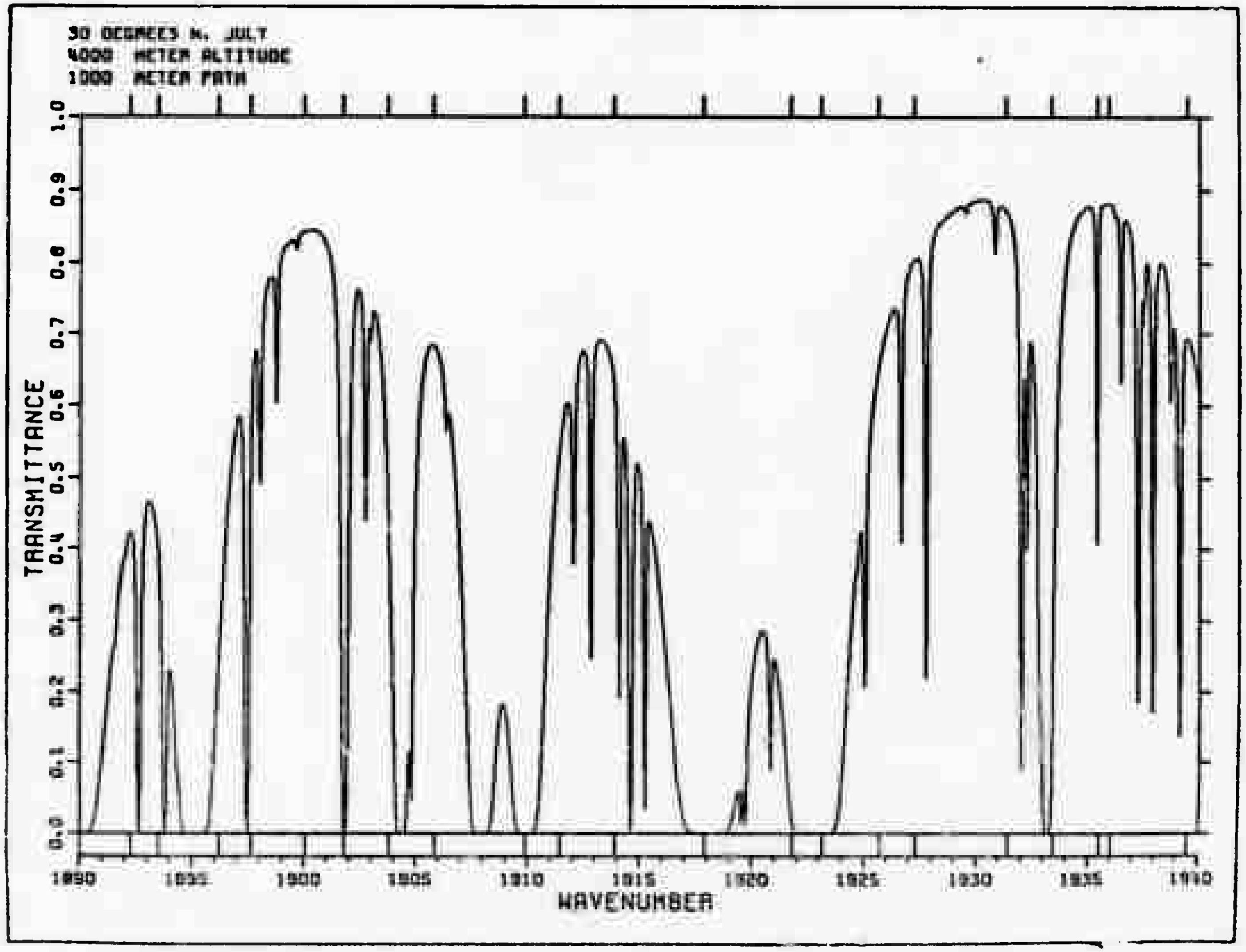


Fig. 14. Theoretical transmittance vs wavenumber for the indicated conditions.

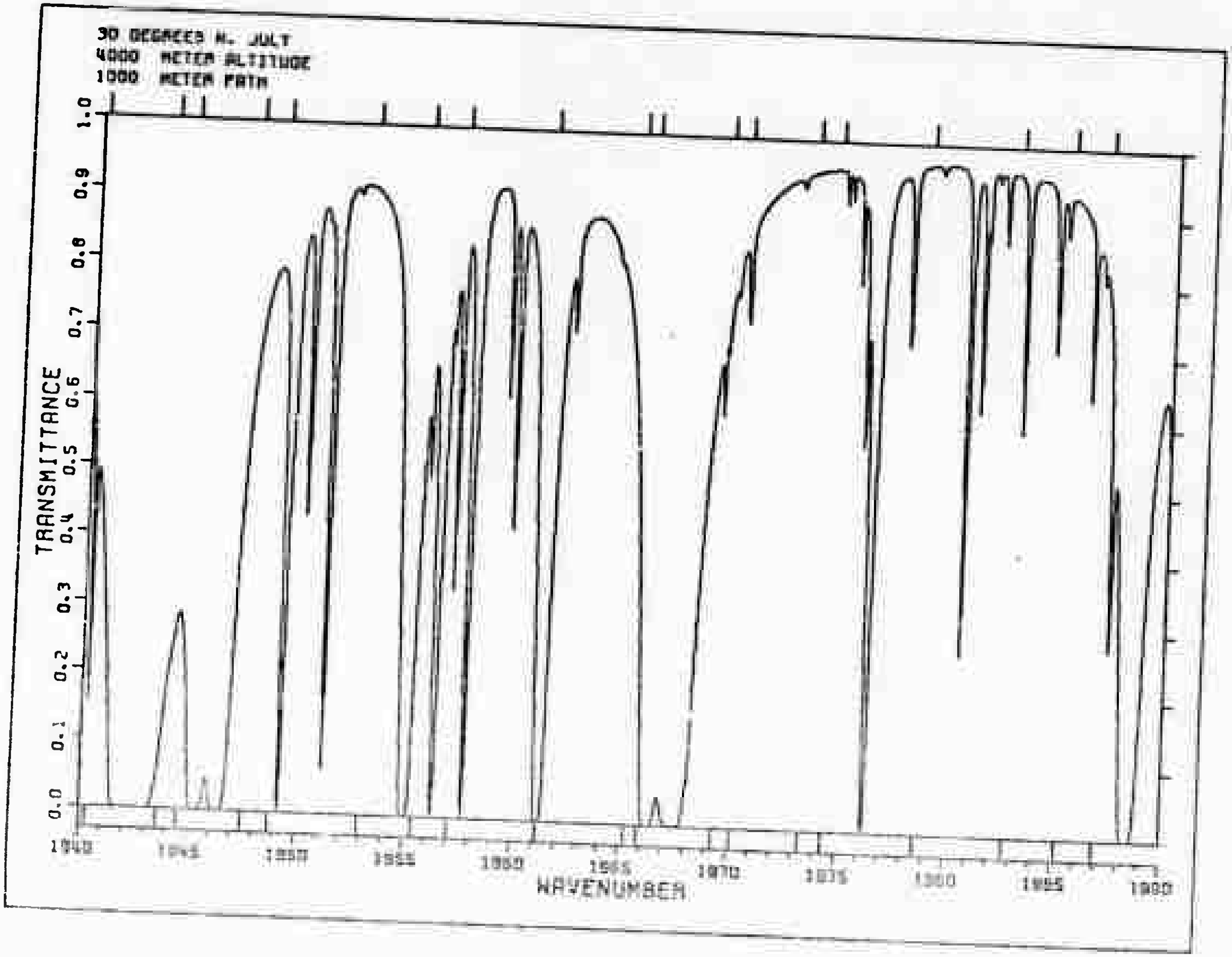


Fig. 15. Theoretical transmittance vs wavenumber for the indicated conditions.

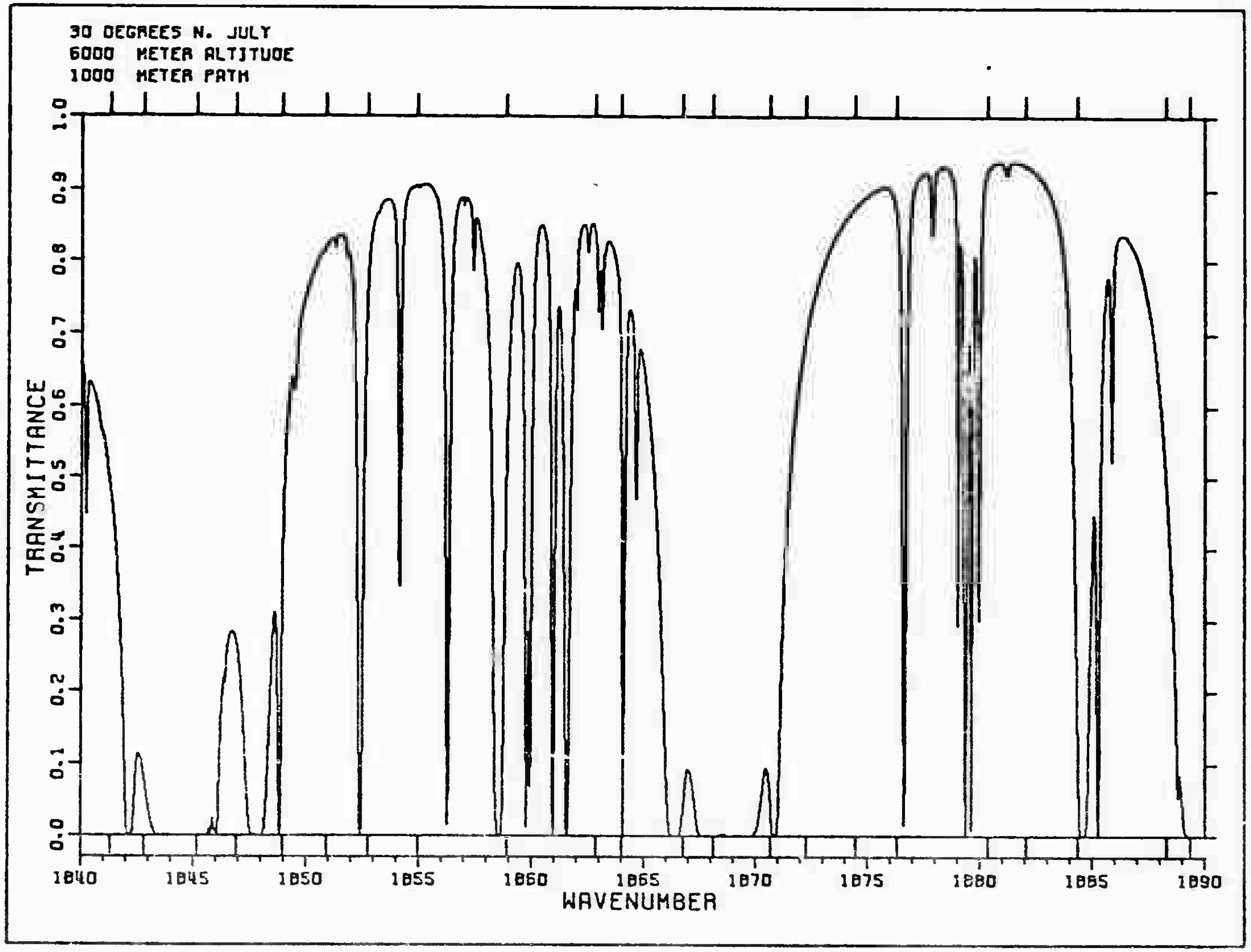


Fig. 16. Theoretical transmittance vs wavenumber for the indicated conditions.

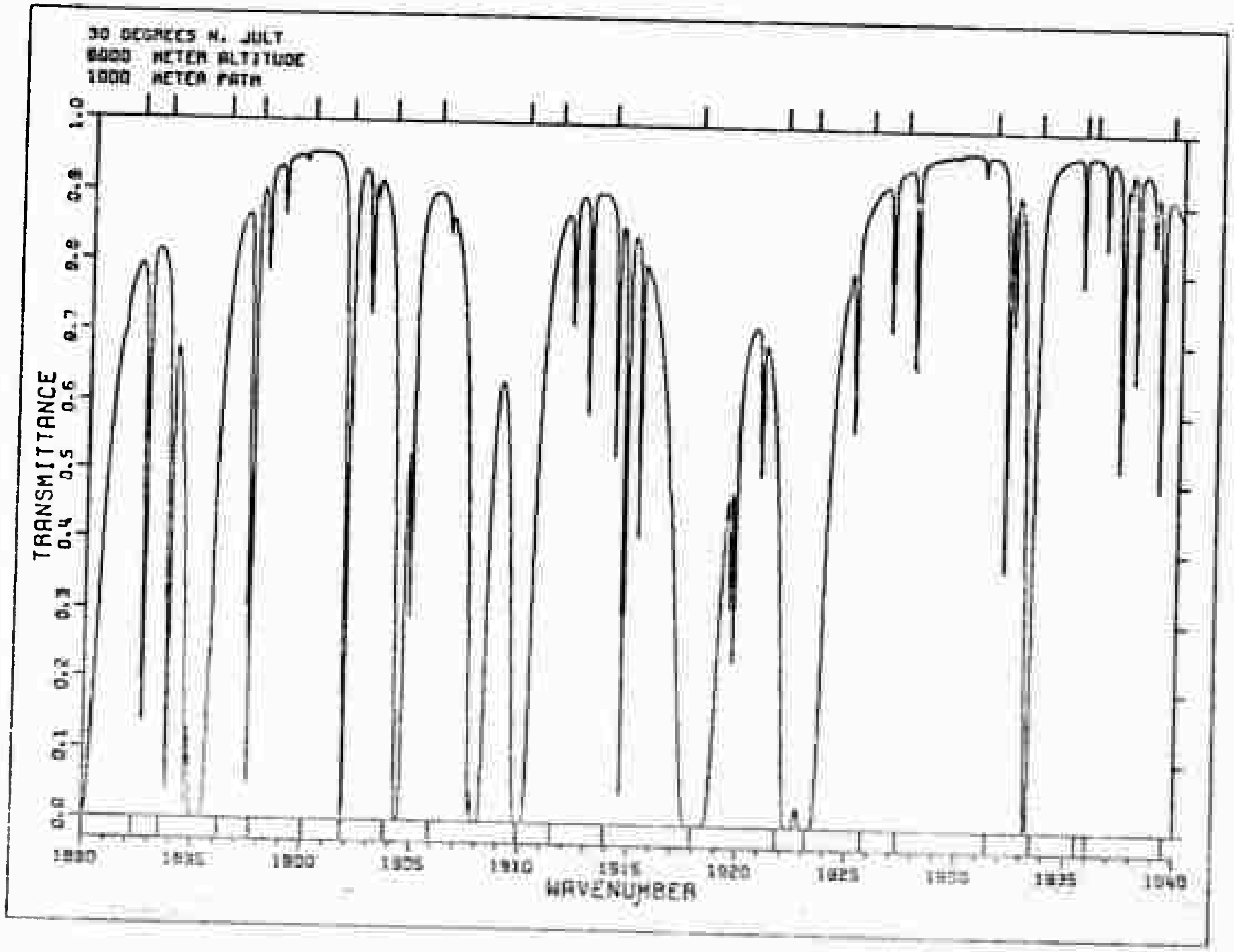


Fig. 17. Theoretical transmittance vs wavenumber for the indicated conditions.

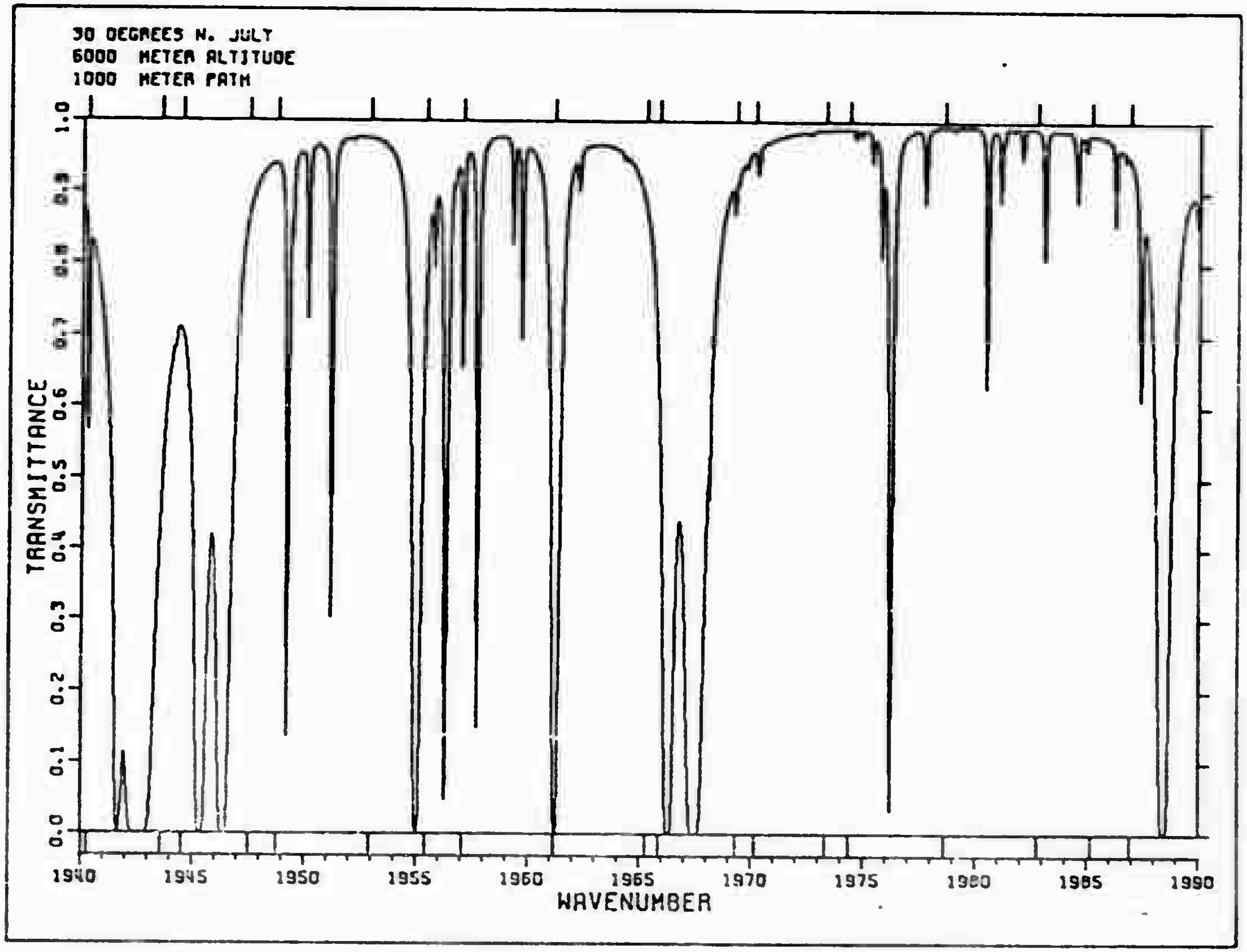


Fig. 18. Theoretical transmittance vs wavenumber for the indicated conditions.

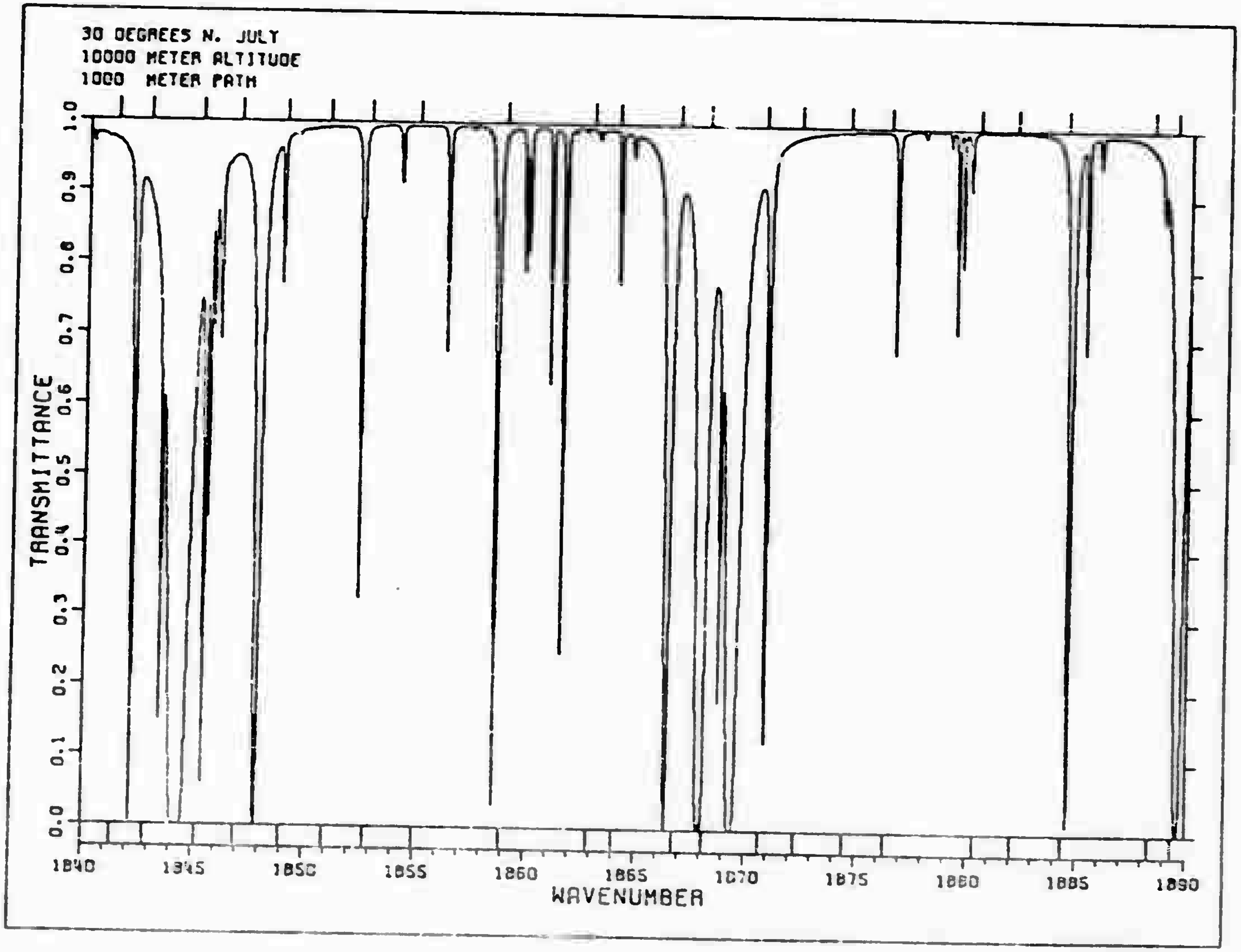


Fig. 19. Theoretical transmittance vs wavenumber for the indicated conditions.

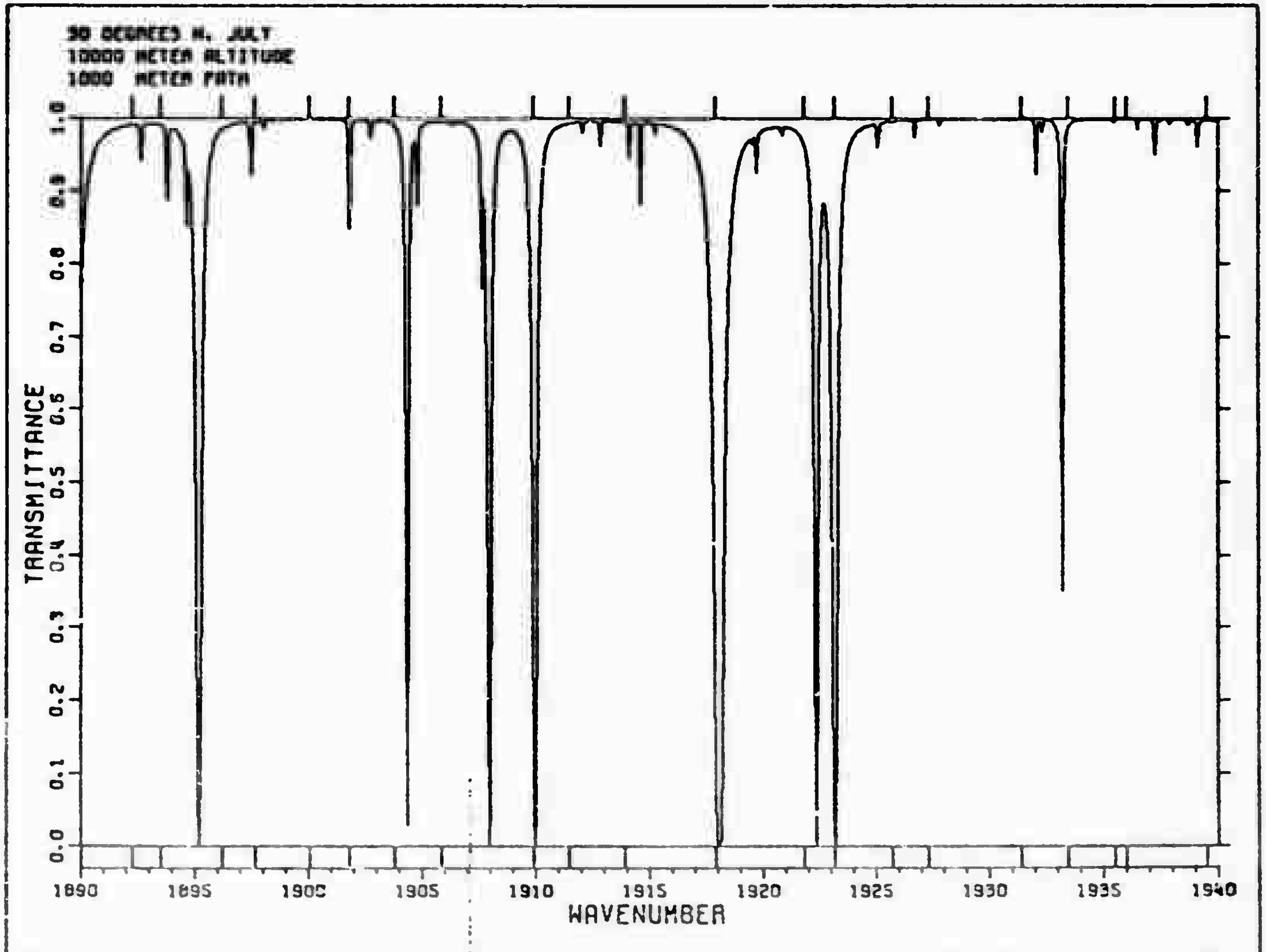


Fig. 20. Theoretical transmittance vs wavenumber for the indicated conditions.

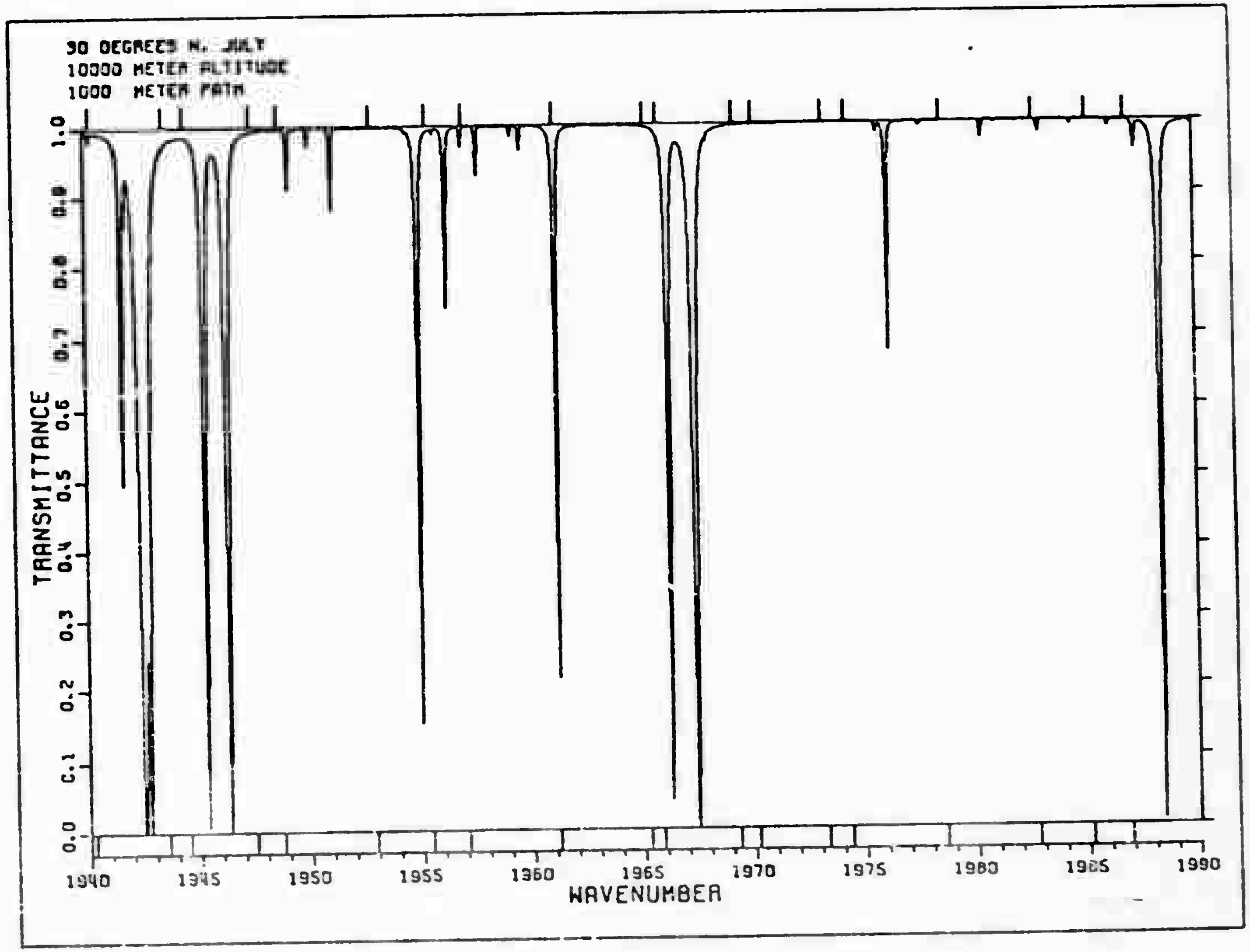
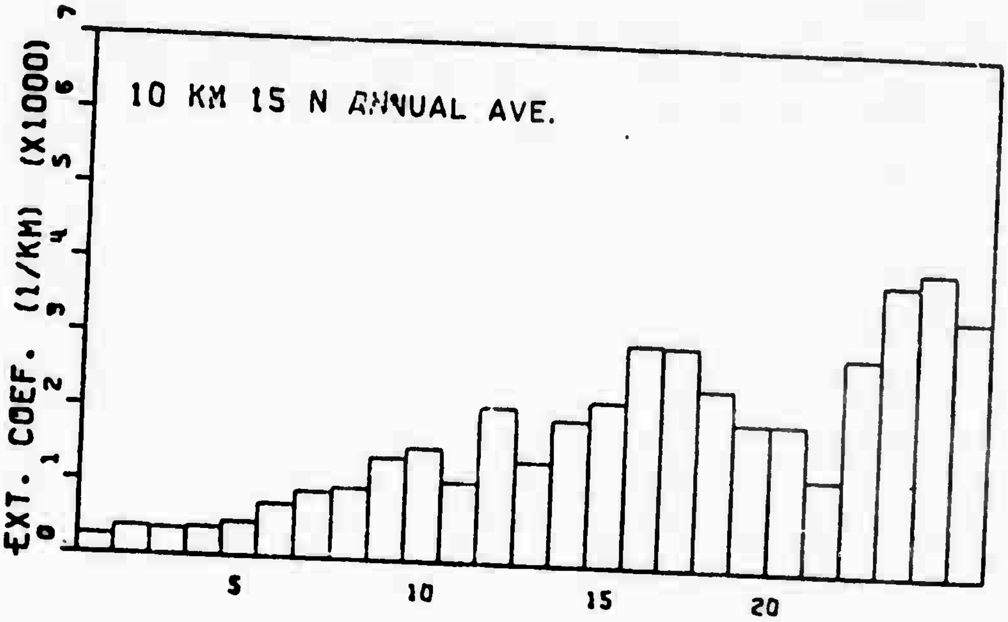


Fig. 21. Theoretical transmittance vs wavenumber for the indicated conditions.



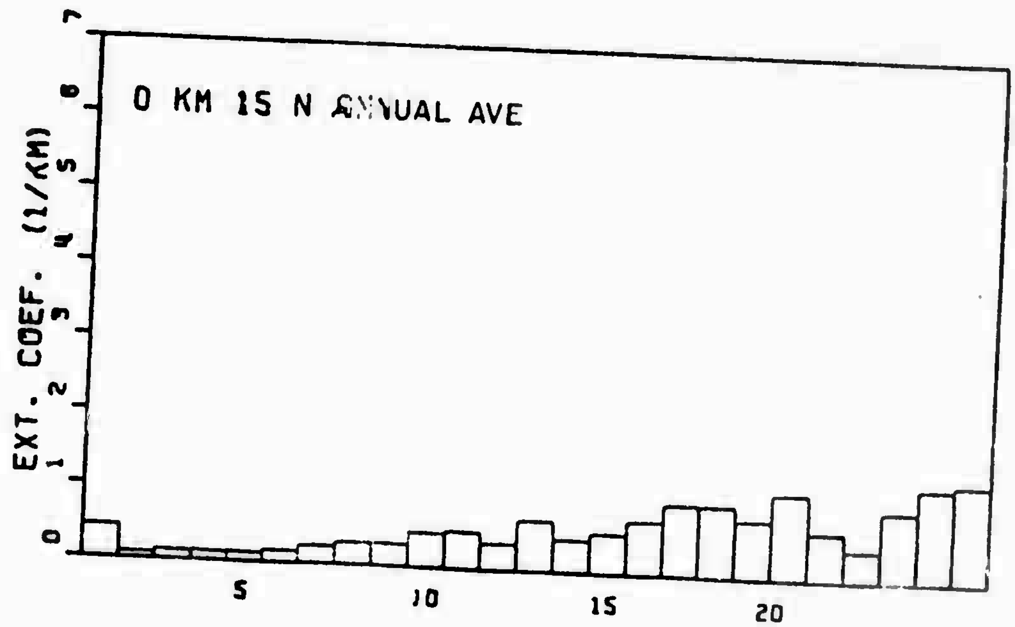


Fig. 22. Relative values of extinction coefficients at wavenumbers of 25 CO laser emission lines for the indicated parameters.

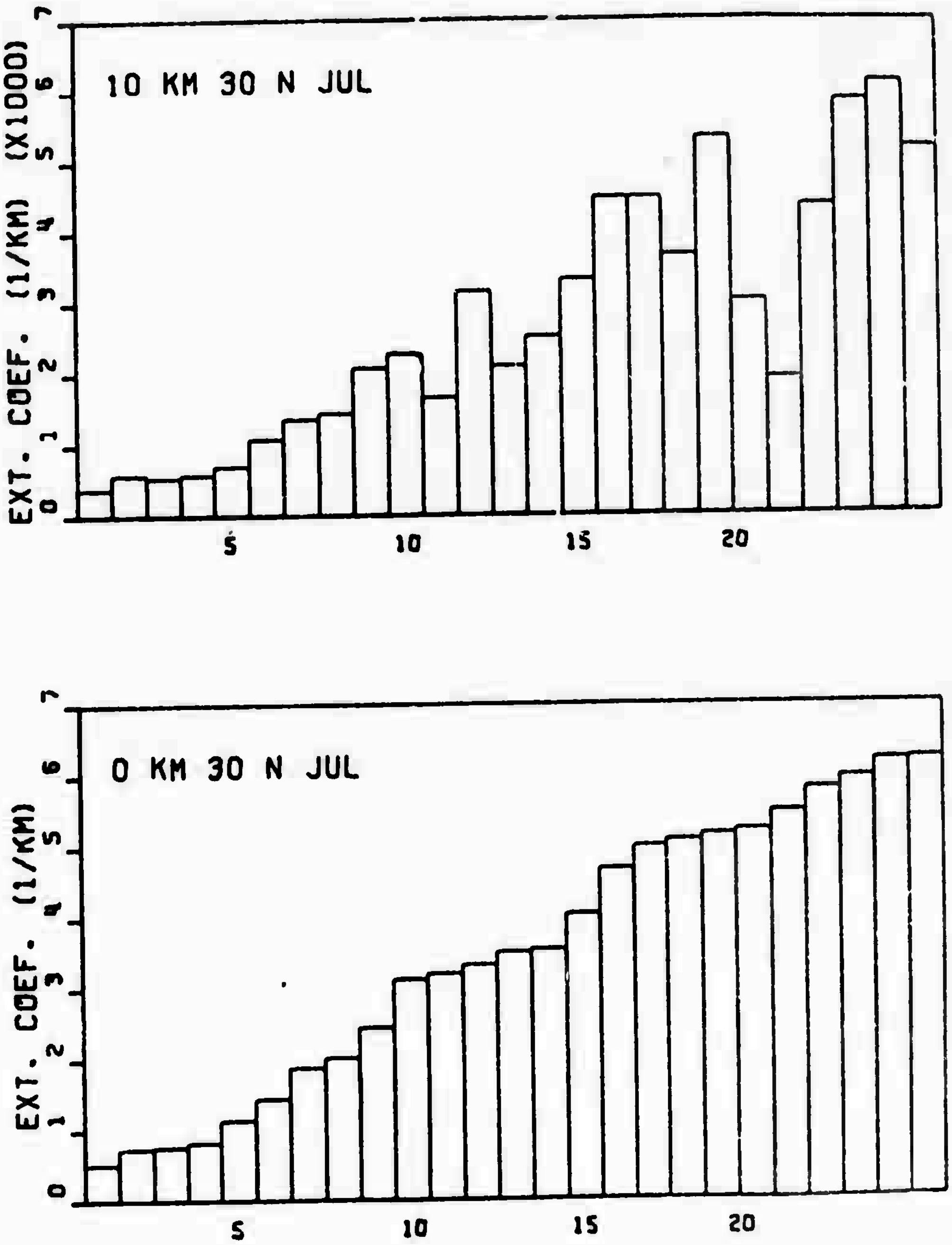


Fig. 23. Relative values of extinction coefficients at wavenumbers of 25 CO laser emission lines for the indicated parameters.

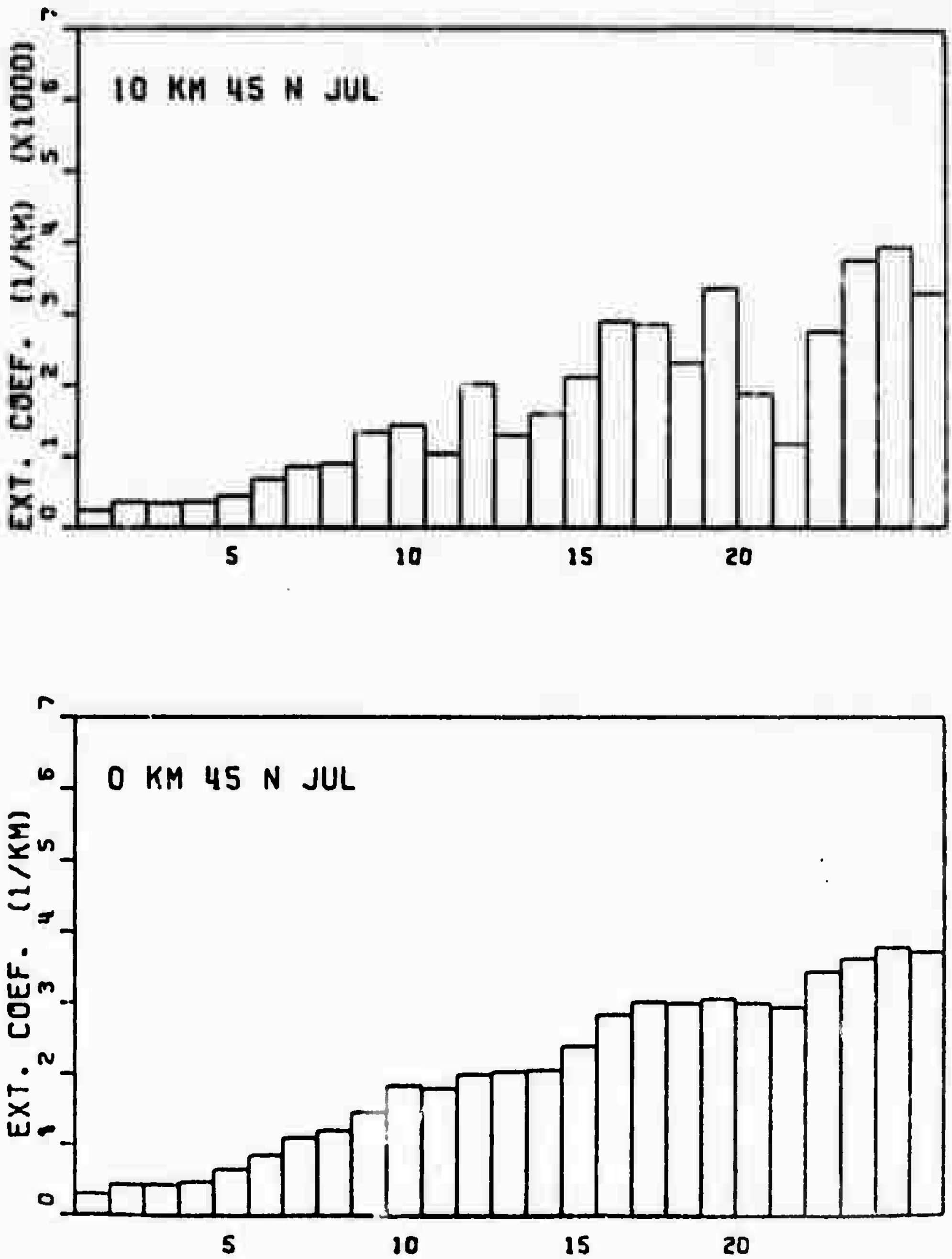


Fig. 24. Relative values of extinction coefficients at wavenumbers of 25 CO laser emission lines for the indicated parameters.

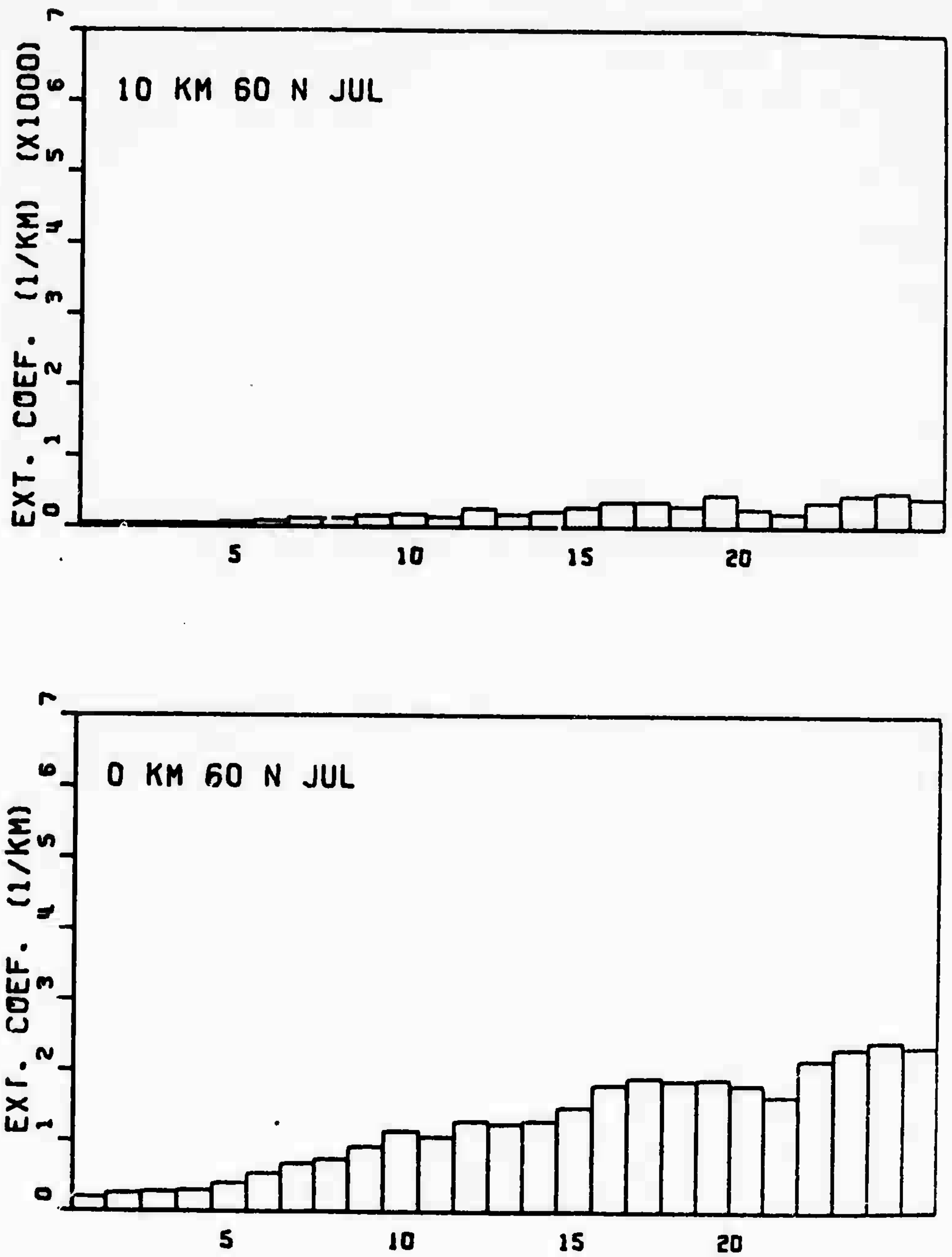


Fig. 25. Relative values of extinction coefficients at wavenumbers of 25 CO laser emission lines for the indicated parameters.

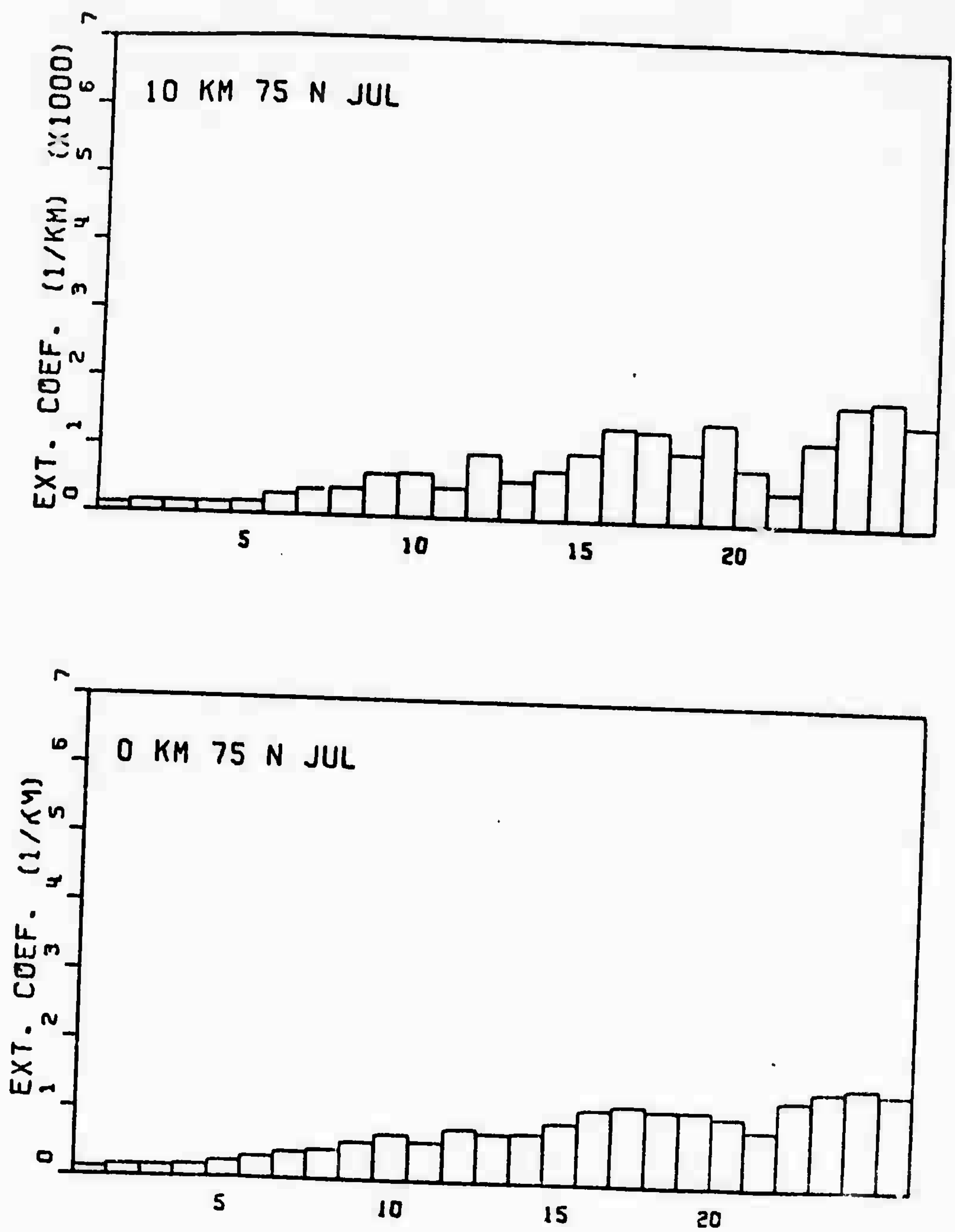


Fig. 26. Relative values of extinction coefficients at wavenumbers of 25 CO laser emission lines for the indicated parameters.

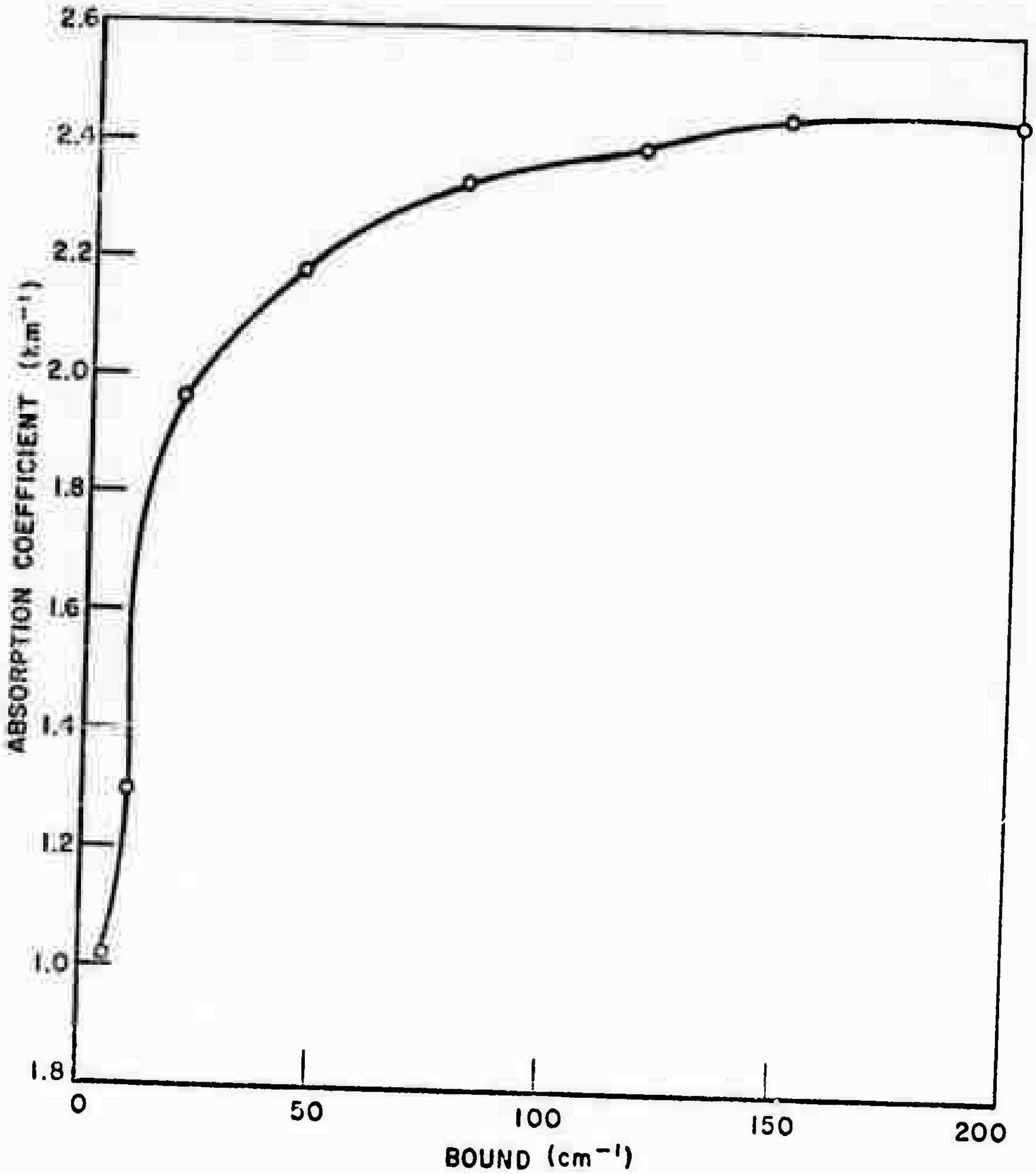


Fig. 27. Calculated absorption coefficient at 1900.043 cm^{-1} vs BOUND. All other parameters are constant.

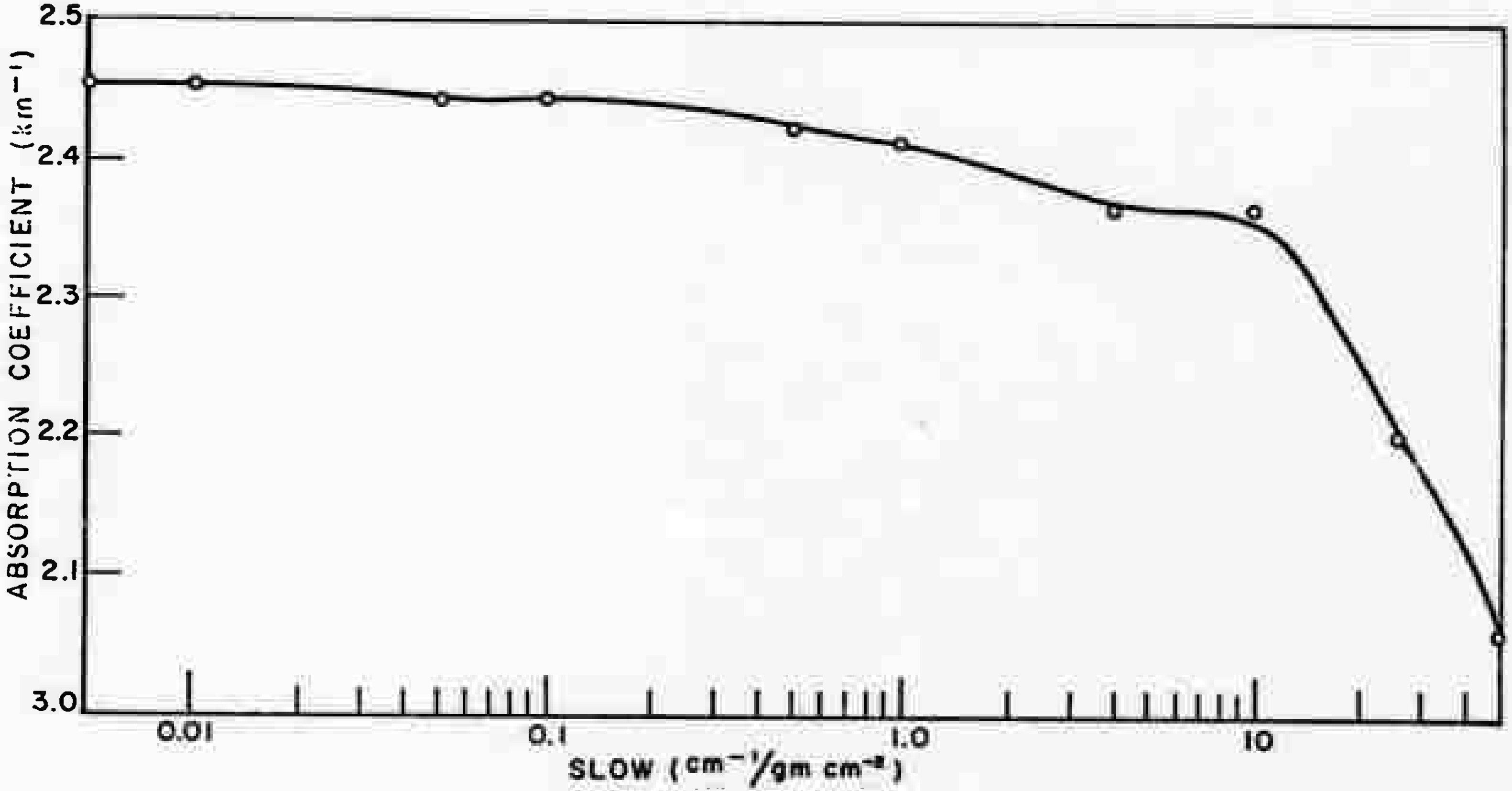


Fig. 28. Calculated absorption coefficient at 1900.043 cm^{-1} vs SLOW.

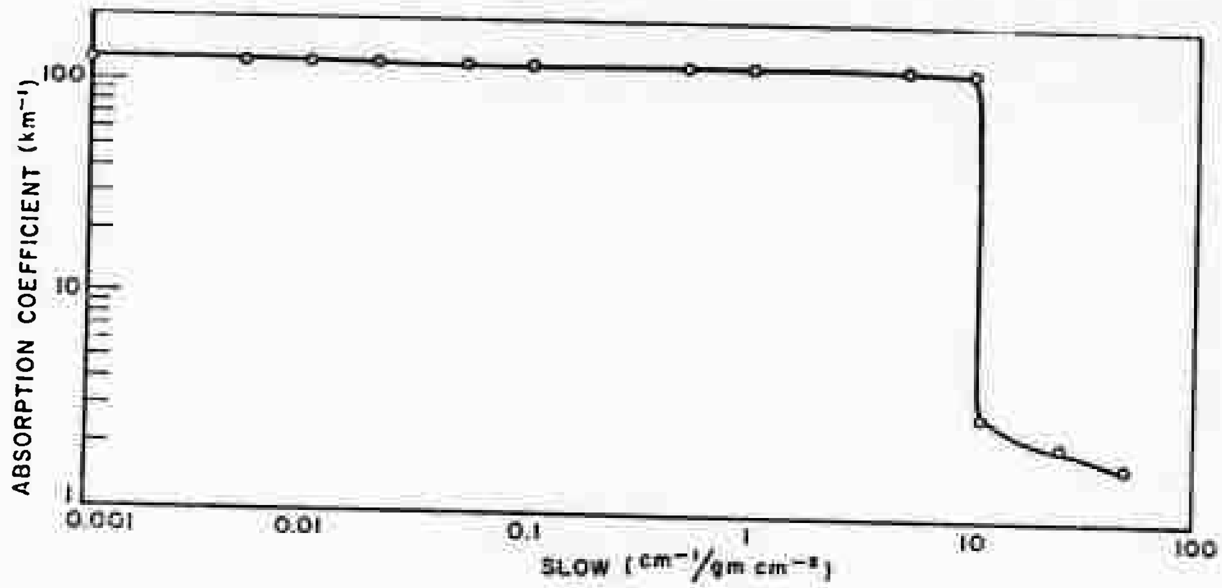


Fig. 29. Calculated absorption coefficient at 1901.779 cm^{-1} vs SLOW.

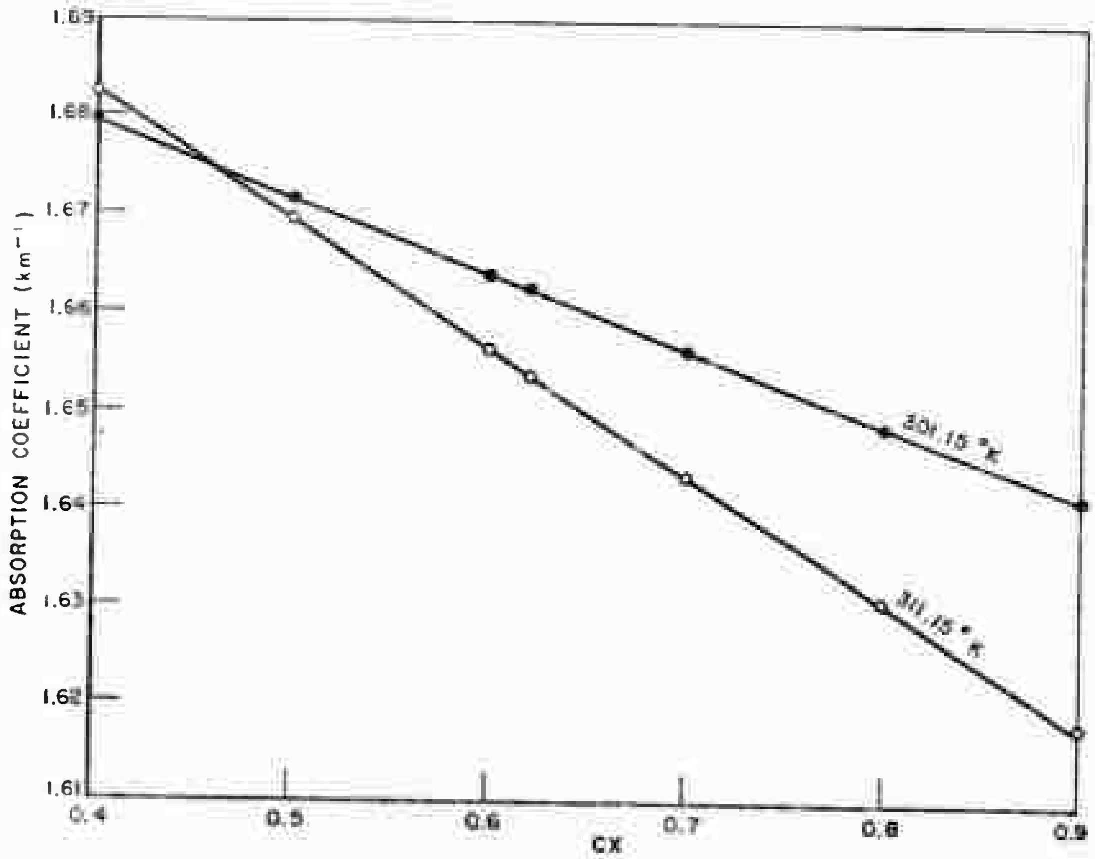


Fig. 30. Calculated absorption coefficient at 1901.043 cm^{-1} vs CX (power law exponent of the temperature dependence of the half-width).

Effect of Changing the Wavenumber at which the Absorption Coefficient is Calculated

Changing the wavenumber, i.e., the laser line frequency, of the absorption coefficient calculation evaluates the possible error in the locations of the molecular absorber lines as well as that of the laser. Again the absorption coefficients near 1900.043 cm^{-1} and 1901.779 cm^{-1} were calculated. Since no strong water lines are near 1900.043 cm^{-1}, the variation of the absorption coefficient with wavenumber is expected to be small; however, near 1901.779 cm^{-1} a large variation is expected due to the effect of the nearby water line at 1901.82 cm^{-1}. The results of these calculations are shown in Figures 31 and 32. The positions of the CO laser lines are known to about 0.006 cm^{-1} (7) while the majority of the water lines are known to only 0.5 cm^{-1} (3). Thus the uncertainty in the value of the absorption coefficient may be appreciable due to the uncertainty of the position of the CO laser lines and the molecular absorber lines.

Effect of Line Shape

A Lorentzian line shape is expected if the broadening of the lines is due to binary collisions between molecules at pressures near one atmosphere. At pressures near one torr Doppler effects determine the line shape and at intermediate pressures the combined effects lead to a Voigt profile for the line shape. A FORTRAN program to calculate the Voigt profile, written by Young[8], was used with the program SLANT to calculate the absorption coefficient between 0 and 10 km for the wavenumbers 1900.043 cm^{-1} and 1901.779 cm^{-1}. Even at the highest altitude (lowest pressure) the calculated absorption coefficient using a Voigt profile was within 1/2% of the absorption coefficient using a Lorentizian profile. Thus a Voigt profile does not need to be used for this altitude range.

The second study involving line shape assumed a Lorentsian line shape within 2 cm^{-1} of line center and a profile that decreased as $(\Delta r)^{-\gamma}$ for wavenumbers greater than 2 cm^{-1} from line center, where Δr is the interval from the center of the absorbing line to the position at which the absorption calculation is being made. For

wavenumbers greater than several half-widths from line center, r equal to 2.0 is a good approximation to the Lorentz line shape. There has been some evidence obtained using tunable laser diodes that for certain water vapor lines with high vibrational quantum numbers r should be greater than 2.0.[7] Figures 33 and 34 show the dependence of the calculated absorption coefficient on r at the CO frequencies 1900.043 cm^{-1} and 1978.609 cm^{-1}. Both these wavenumbers are in "windows" of the water vapor spectrum so that the absorption coefficients strongly depend upon the value of r as is seen in these figures.

These parametric studies were made to illustrate the importance of the various parameters and not to calculate the actual absorption coefficients at the specified wavenumbers; however, several general conclusions about the transmittance calculations in the spectral region of 5.0 μm can be drawn.

1) To calculate accurate absorption coefficients, water vapor lines as far as 120 cm^{-1} from the wavenumber of the CO laser line should be included in the calculations.

2) Water vapor lines whose strengths are less than 0.1 $cm^{-1}/gm\ cm^{-2}$ may be neglected.

3) The temperature dependence of the half-widths for water vapor must be relatively well known for accurate calculations.

4) A line shape given by the Lorentz formula gives essentially the same absorption coefficient as a Voigt line shape for the pressures to be used in this program.

5) If the line shape is not given by the Lorentz formula in the "wings" of the lines, appreciable differences in the calculated absorption coefficients are probable.

6) Small uncertainties in the position of the CO laser lines used the water vapor lines can lead to large uncertainties is the calculated absorption coefficients.

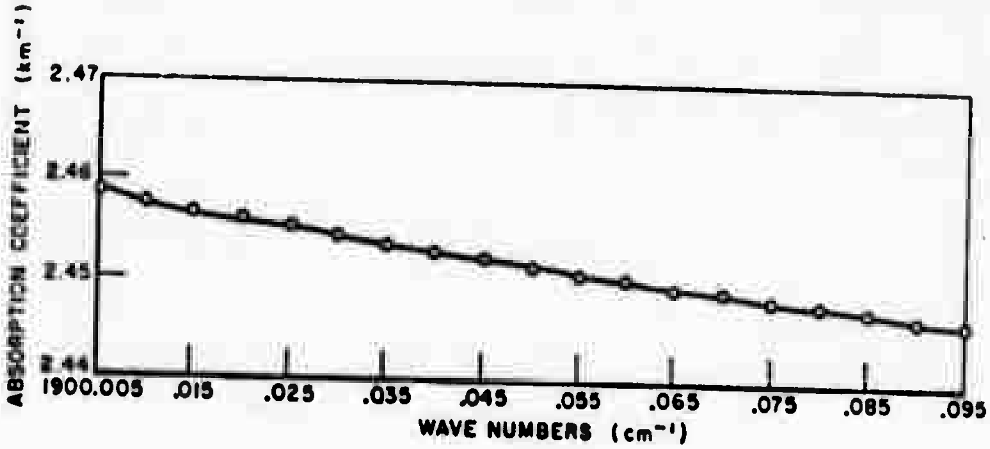


Fig. 31. Calculated absorption coefficient vs wavenumber near 1900.043 cm^{-1}.

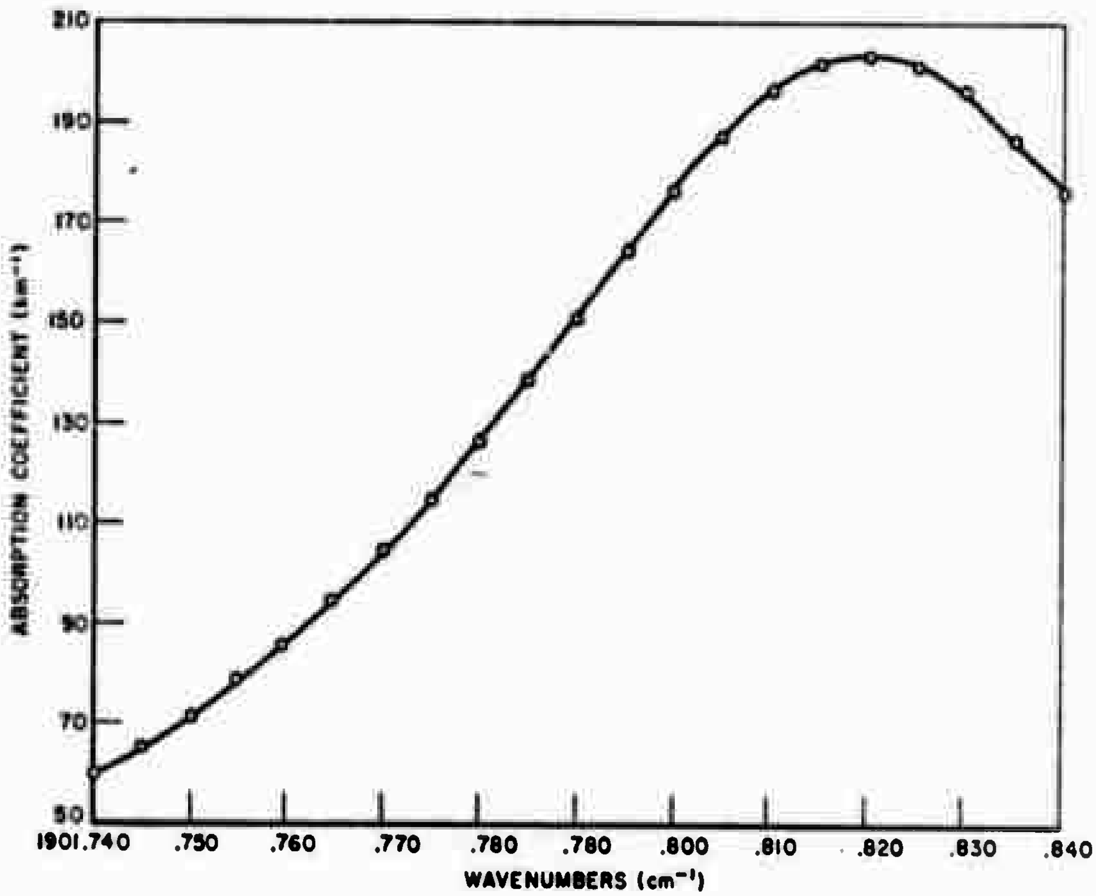


Fig. 32. Calculated absorption coefficient vs wavenumber near 1901.779 cm^{-1}.

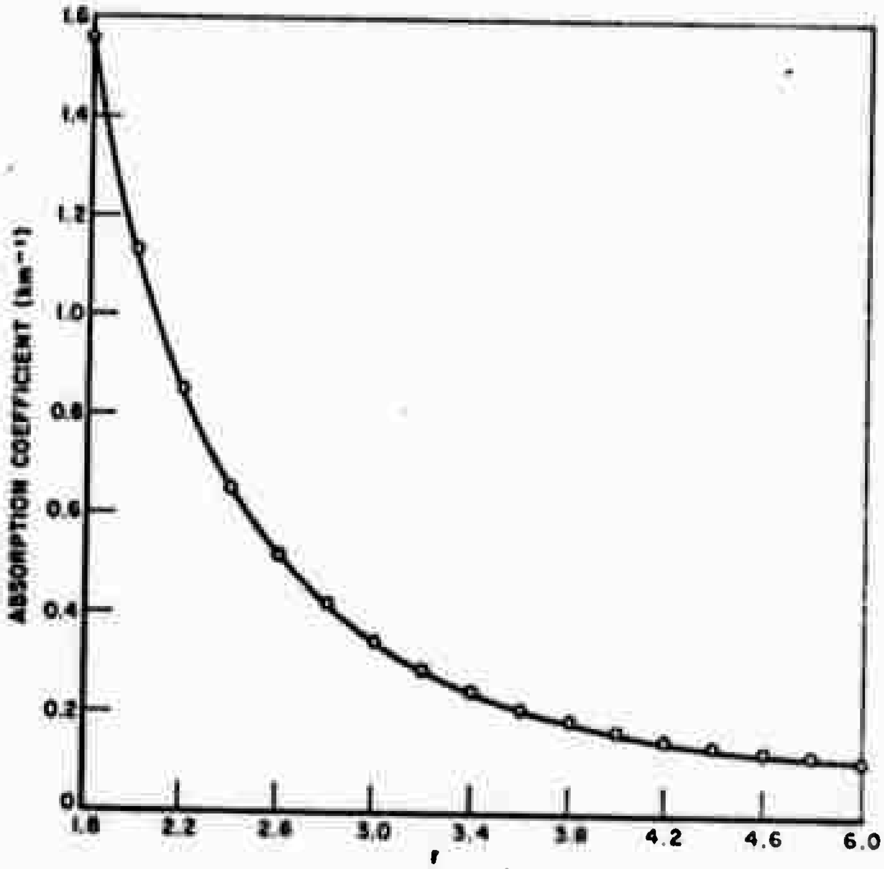


Fig. 33. Calculated absorption coefficient at 1900.043 cm^{-1} vs r, where r is the power law exponent describing the dependence of the absorption coefficient of all absorbing lines at wavenumbers greater than 2.0 cm^{-1} from the center of the absorbing line.

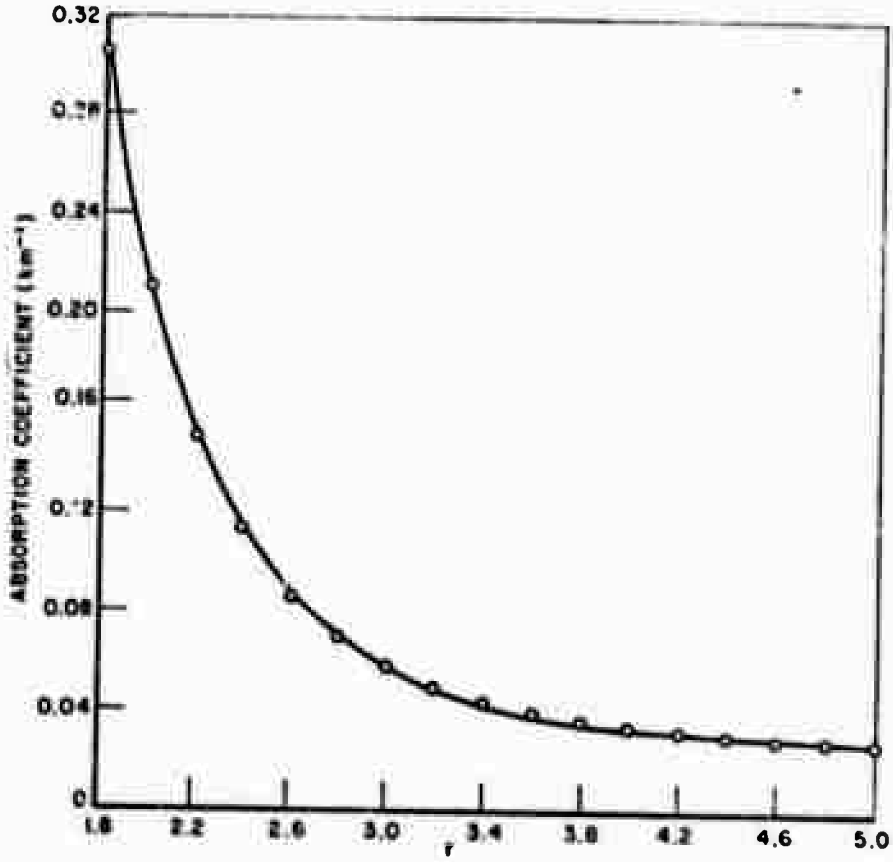


Fig. 34. Calculated absorption coefficient at 1978.609 cm^{-1} vs r, where r is the power law exponent describing the dependence of the absorption coefficient of all absorbing lines at wavenumbers greater than 2.0 cm^{-1} from the center of the absorbing line.

III. EXPERIMENTAL

The CO laser was received from Lincoln Laboratory on December 14, 1971. While at Lincoln Lab instruction in its operation was obtained and the laser was filled with the same mixture of gases reported in our last report.[1] The experimental apparatus had previously been prepared so that only positioning the laser in the proper place was necessary once it was obtained. This preparation for the laser included moving a 2 ton optical bench in place, assembling the electronics for the laser, installing the refrigeration system for cooling the laser, aligning the mirrors in the absorption cell, adding pressure measuring instruments, a heat pump, and circulating fans to the absorption cell, and installing the reference and signal detectors and their associated electronics. The XDS 910 computer was also replaced with a newer model, an XDS 920, which has a larger core and a greater versatility. Modifications were made to the previous software to make it compatible with the newer computer and the absorptance measurement experiment.

A test of the possible adsorption of water vapor on the walls of the absorption cell showed that adsorption effects are small. An 8.28 torr sample of water vapor was placed in the cell and the pressure of the cell was monitored. After 4 hours the pressure had decreased to 8.13 torr. Nitrogen was then added to the cell to a total pressure of 760 torr and allowed to mix with the water vapor. The dewpoint of the mixture was monitored and after the gases were mixed a change of $1/2^{o}F$ had occurred during the 16 hour period. This change corresponds to the resolution of the Dew Point Hygrometer. While adsorption of water vapor on the walls is small it must be considered in order to achieve measurement of absorption coefficients accurate to $\pm 1\%$. Thus monitoring the water vapor in the cell during the experiment with a mass spectrometer gas analyzer is considered important.

Shortly after its arrival, the CO laser was operated and various portions of the equipment were tested with the following results.

1) The refrigeration system could maintain the temperature of the alcohol leaving the operating laser at $-85^{o}C$.

2) The wander of the infrared beam through the cell as gases are mixed in the cell prevents a thermocouple or another small area detector being used, if high accuracy is desired. The system was redesigned to use a thermopile detector of much larger area.

3) The techniques of obtaining data during the experiment were tested and modified where appropriate.

During these tests preliminary data on the absorptance of about 12 CO laser lines was obtained for a single partial pressure of water vapor which was pressure broadened with nitrogen up to one atmosphere. The precision of these measurements is low (~15%), but with the proposed experimental changes and improved measuring techniques a goal of 2% accuracy of the transmittance measurements is realistic for lower total pressures. Above 1/2 atmosphere the feasible accuracy is somewhat less due to beam wander caused by the thermal and mass inhomogenities of the gas mixture. 5% accuracy of the transmittance measurements with a pressure in the cell of one atmosphere is anticipated. We have decided not to report the first measurements at this time due to their limited accuracy.

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APPENDIX A

The calculations presented in this report and the previous quarterly report have used nine atmospheric models: (1) 15°N Annual, 30°N July, 45°N July, 60°N July, 75°N July, 30°N January, 45°N January, 60°N January, and 75°N January. These models are derived from the ESSA U.S. Standard Atmosphere Supplements, 1966 (2).

For reference purposes all nine models are reproduced below. As explained in Report 3271-1 the approximately eight points of data between 0 and 10 km are used with a polynomial curve fit routine to produce input data for the slant path transmittance program.

ATMOSPHERIC MODEL FOR 15^{o}N LATITUDE, ANNUAL

ALTITUDE METER	TEMPERATURE DEG K	EFFECTIVE* PRESSURE ATM	H20 PRESS. TORR
0.0	299.65	1.1026	19.5
1000.0	293.65	.9634	13.5
2000.0	287.65	.8432	9.3
2500.0	286.95	.7527	4.12
4000.0	276.90	.6362	2.14
6000.0	263.50	.4900	0.776
10000.0	236.70	.2824	0.048

ATMOSPHERIC MODEL FOR 30^{o}N LATITUDE, JULY

0.0	301.15	1.1191	22.59
1000.0	293.65	.9543	11.69
2000.0	288.15	.8348	7.65
3000.0	282.65	.7336	5.34
4000.0	277.15	.6407	3.02
6000.0	266.15	.4920	1.06
8000.0	252.15	.3760	0.357
10000.0	238.15	.2839	0.072

ATMOSPHERIC MODEL FOR 30^{o}N LATITUDE, JANUARY

0.0	287.15	1.0581	9.59
1000.0	284.15	.9308	6.86
2000.0	281.15	.8144	4.01
3000.0	274.65	.7140	2.30
4000.0	268.15	.6250	1.11
6000.0	255.15	.4792	.338
8000.0	242.15	.3636	.090
10000.0	229.15	.2722	.024

*This pressure is the effective pressure for water vapor. It accounts for the fact that the water vapor continuum depends much more on self-broadening due to water vapor molecules than broadening due to other atmospheric molecules.

ATMOSPHERIC MODEL FOR 45°N LATITUDE, JULY

ALTITUDE METER	TEMPERATURE DEG. K	EFFECTIVE* PRESSURE ATM	H2O PRESS. TORR
0.0	294.15	1.0739	14.0
1000.0	289.65	.9385	9.14
2000.0	285.15	.8214	5.76
3000.0	279.15	.7179	3.17
4000.0	273.15	.6294	1.82
6000.0	261.15	.4831	0.553
10000.0	235.15	.2775	0.047

ATMOSPHERIC MODEL FOR 45°N LATITUDE, JANUARY

0.0	272.15	1.0218	3.25
1000.0	268.65	.8978	2.31
2000.0	265.15	.7881	1.65
3000.0	261.65	.6903	1.05
4000.0	255.65	.600	.565
6000.0	243.65	.4576	.188
8000.0	231.65	.3429	.030

ATMOSPHERIC MODEL FOR 60°N LATITUDE, JULY

0.0	287.15	1.0442	9.01
1000.0	281.75	.9150	5.83
2000.0	276.35	.8038	4.02
3000.0	270.95	.7043	2.55
4000.0	265.55	.6166	1.56
6000.0	253.15	.4703	0.481

*This pressure is the effective pressure for water vapor. It accounts for the fact that the water vapor continuum depends much more on self-broadening due to water vapor molecules than broadening due to other atmospheric molecules.

ATMOSPHERIC MODEL FOR 60°N LATITUDE, JANUARY

ALTITUDE METER	TEMPERATURE DEG K	EFFECTIVE* PRESSURE ATM	H2O PRESS. TORR
0.0	257.15	1.0056	1.01
1000.0	259.15	.8819	1.08
2000.0	255.95	.7718	.841
3000.0	252.75	.6740	.585
3500.0	251.15	.6293	.450
4000.0	247.75	.5872	.332
6000.0	234.15	.4413	.076

ATMOSPHERIC MODEL FOR 75°N LATITUDE, JULY

0.0	278.15	1.0284	5.53
1000.0	275.55	.9049	4.10
2000.0	272.95	.7950	2.92
2500.0	271.65	.7464	2.64
4000.0	261.90	.6101	1.06
6000.0	248.90	.4640	0.298
10000.0	226.65	.2593	0.023

ATMOSPHERIC MODEL FOR 75°N LATITUDE, JANUARY

0.0	249.15	1.0032	0.563
1000.0	252.15	.8755	0.555
1500.0	253.65	.8185	0.580
2000.0	250.90	.7646	0.487
3000.0	245.40	.6653	0.271
4000.0	239.90	.5774	0.145
6000.0	228.90	.4309	0.038

*This pressure is the effective pressure for water vapor. It accounts for the fact that the water vapor continuum depends much more on self-broadening due to water vapor molecules than broadening due to other atmospheric molecules.

APPENDIX B

This table lists the extinction coefficient per km for the 25 best CO laser lines as determined from the 0 km, 30°N July model.

LINE NO.	WAVENUMBER (cm^{-1})	EXT. COEFF. PER KM
1	1978.609	0.524
2	1974.357	0.731
3	1973.310	0.758
4	1982.766	0.819
5	1985.128	1.143
6	1952.888	1.445
7	1936.002	1.872
8	1931.380	2.022
9	1900.043	2.442
10	1927.282	3.116
11	1970.159	3.197
12	1882.035	3.316
13	1986.918	3.497
14	1948.730	3.532
15	1880.330	4.035
16	1854.927	4.680
17	1905.834	4.994
18	1939.504	5.077
19	1957.070	5.168
20	1969.304	5.211
21	1935.484	5.482
22	1925.700	5.792
23	1874.446	5.950
24	1947.496	6.192
25	1913.892	6.210

ERRATA

The following table is a correction for Report 3271-1 and should be inserted therein.

TABLE 4

TRANSMITTANCE OF SELECTED LASER LINES THROUGH 30°N LATITUDE, JULY MODEL ATMOSPHERE

FREQUENCY (cm^{-1})	BAND	LINE	ABSORPTION COEFFICIENT Km^{-1}	TRANSMITTANCE 1 Km
1978.609	5-4	P15	.479	.620
1974.357	5-4	P16	.659	.518
1982.766	5-4	P14	.719	.487
1952.889	6-5	P15	1.401	.246
1936.003	6-5	P19	1.823	.162
1931.381	7-6	P14	1.994	.136
1900.043	9-8	P9	2.452	.086
1927.282	7-6	P15	3.090	.046
1970.159	5-4	P17	3.169	.042
1986.918	5-4	P13	3.469	.031